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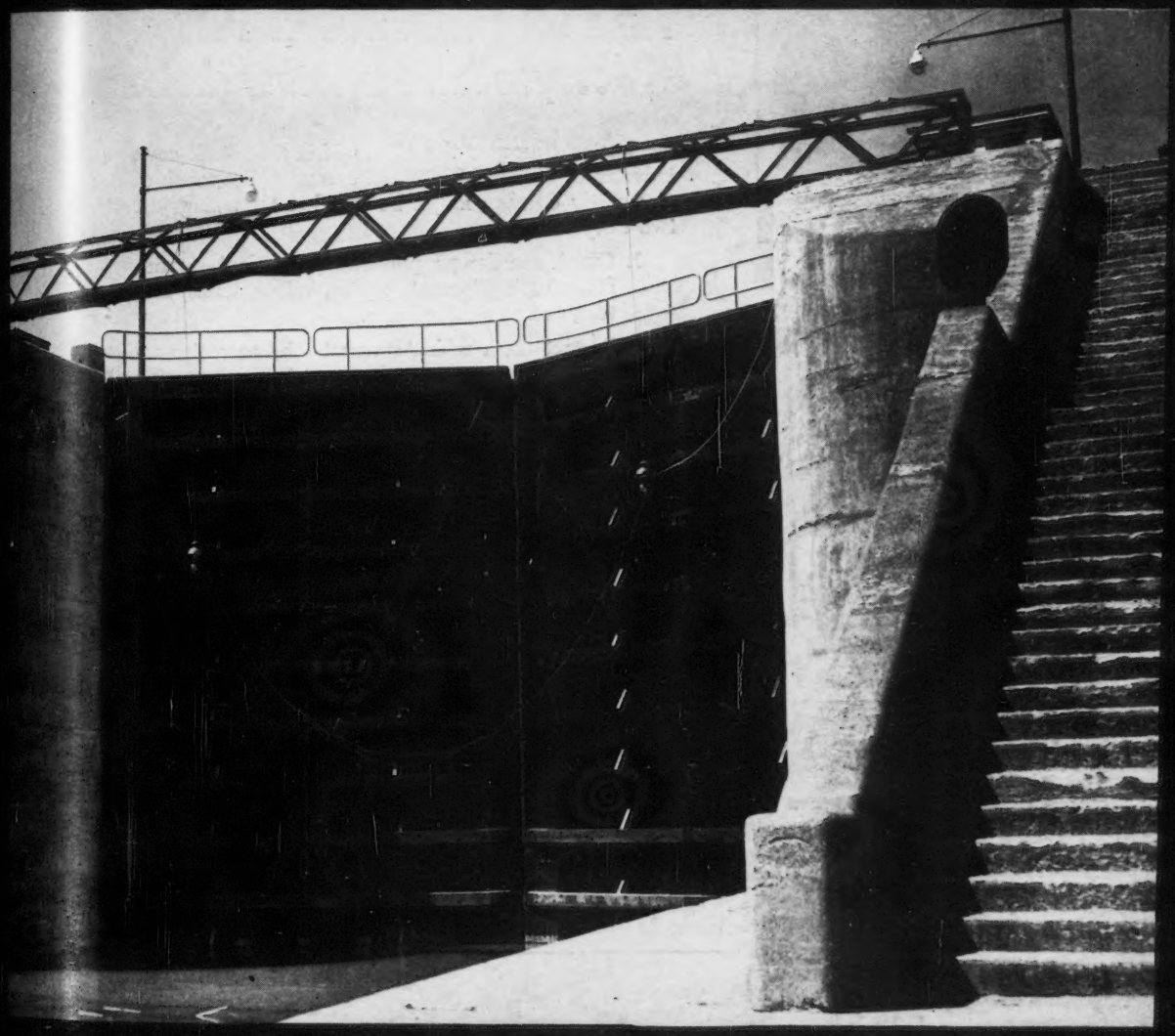

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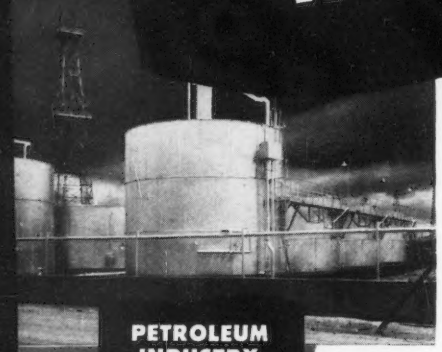

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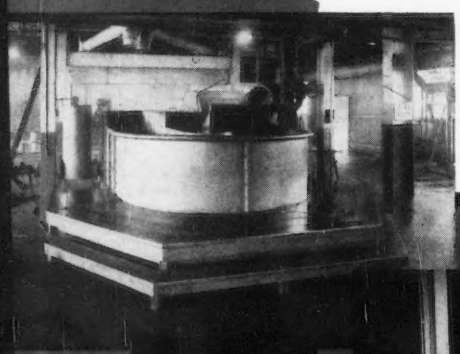

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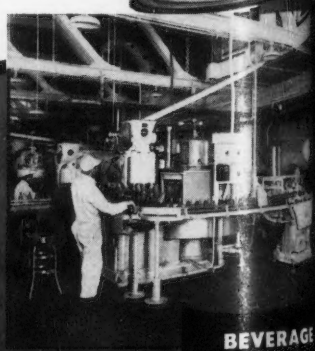

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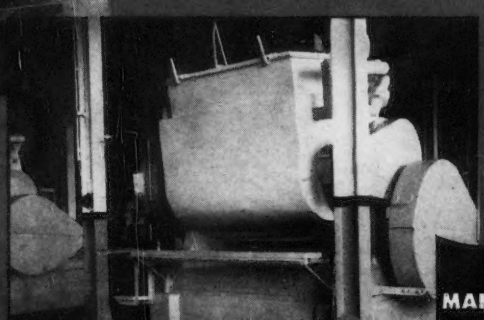

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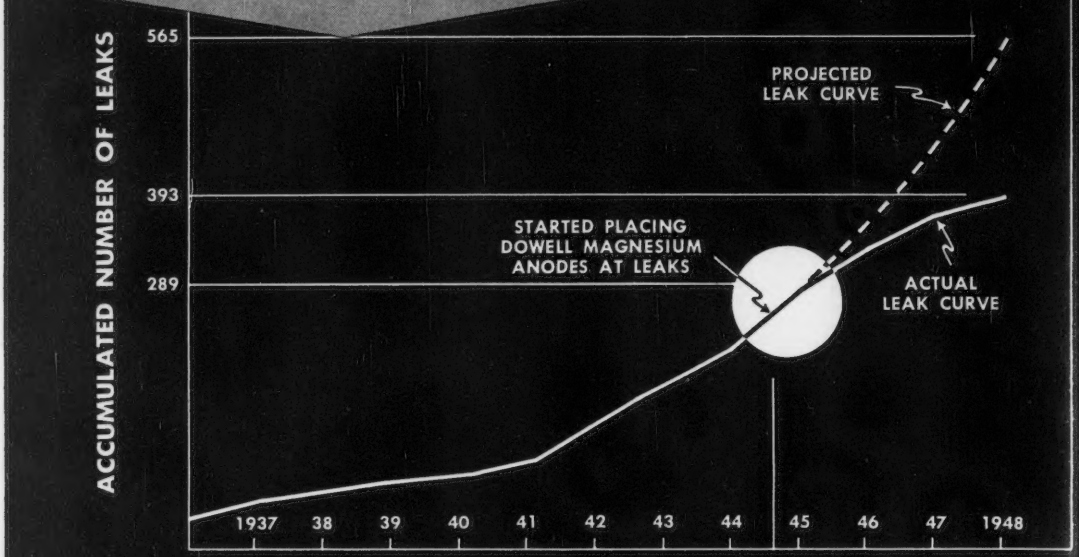

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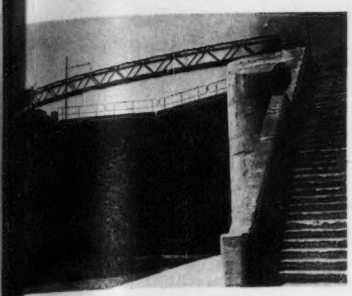

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Entered as second class matter October 31, 1946, at the Post Office at Houston, Texas, under the act of March 3, 1879.

CORROSION is Indexed Regularly by Engineering Index.

CORROSION

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Research and Control

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U. S. A., to provide a permanent record of progress in the control of corrosion as described in papers prepared for the Association and from other sources.

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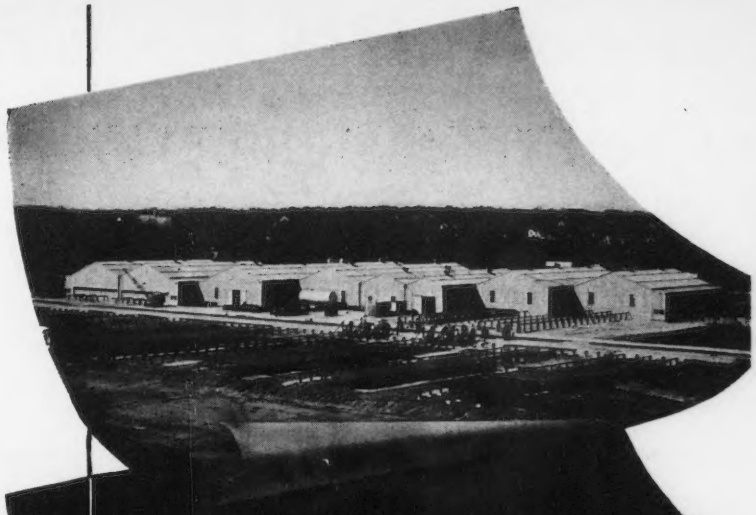

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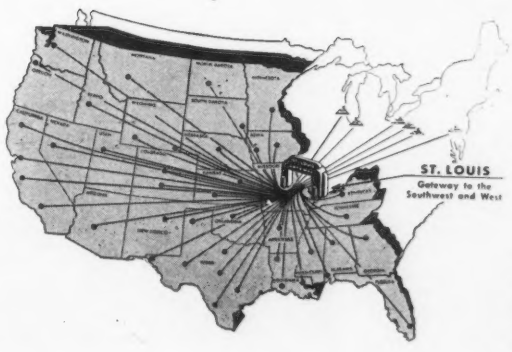

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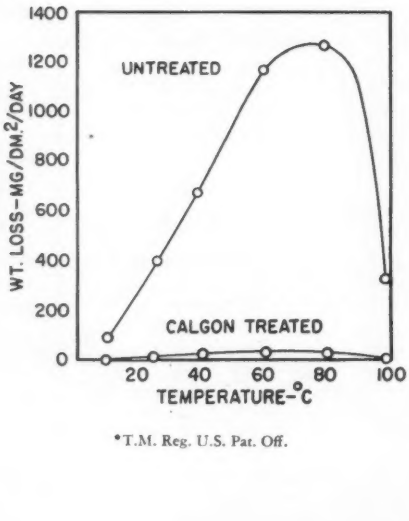

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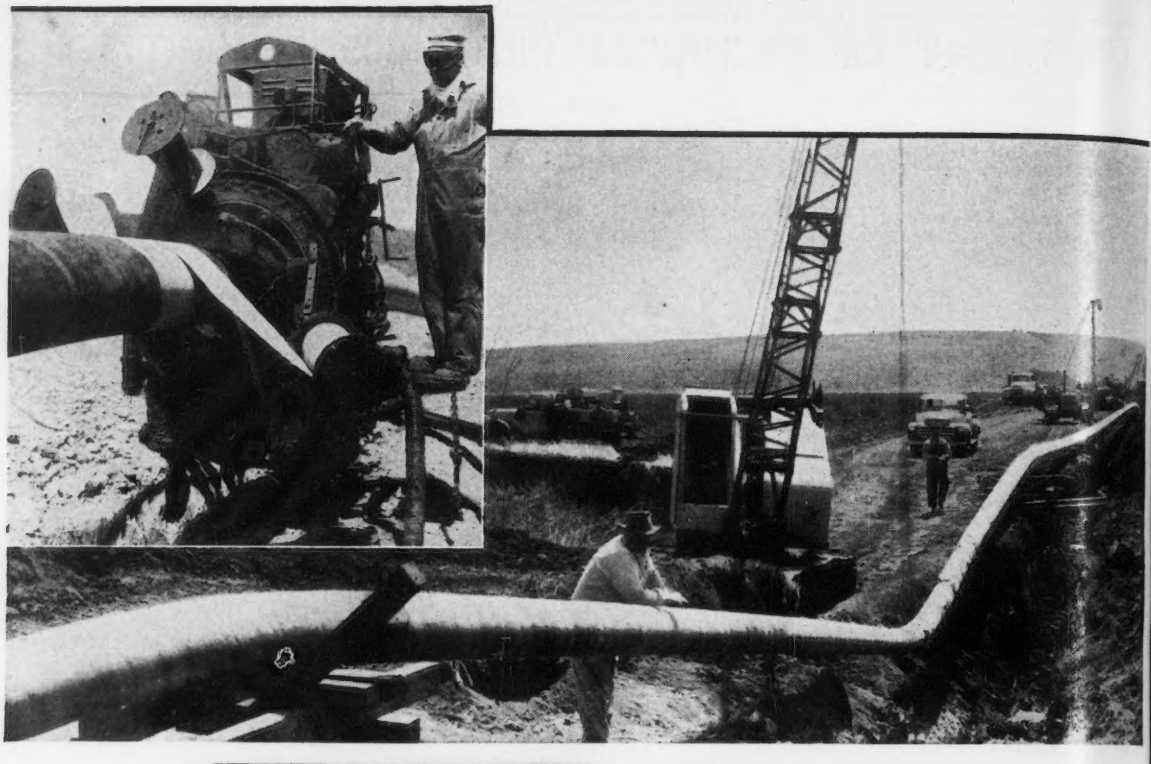

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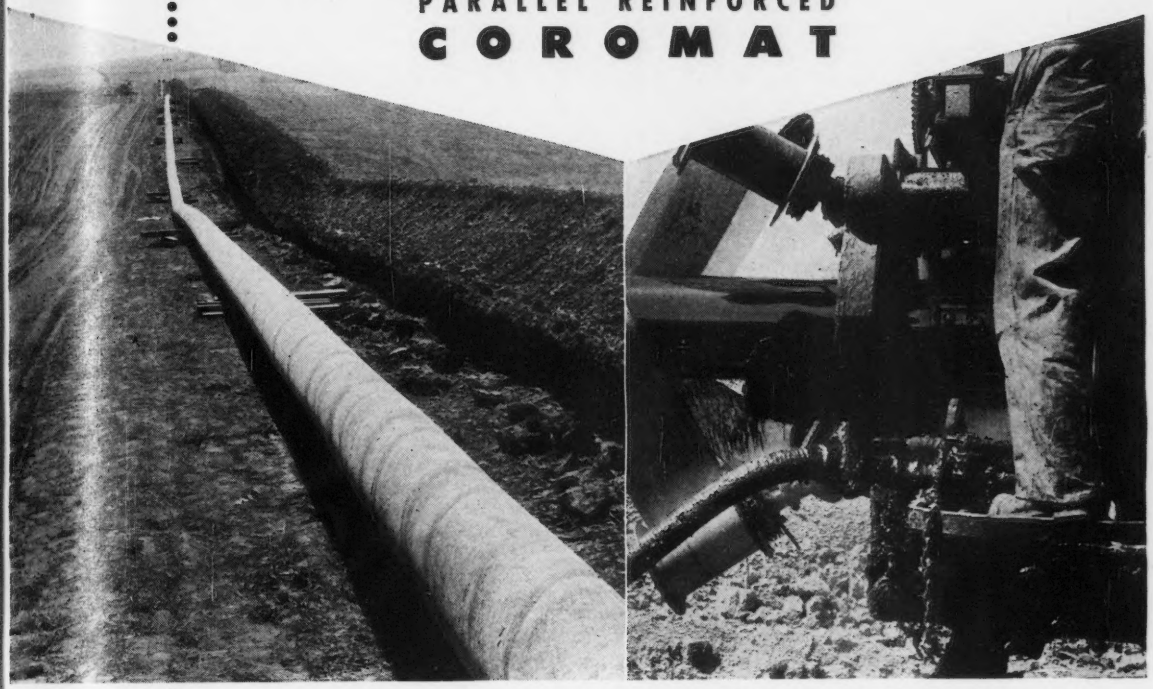

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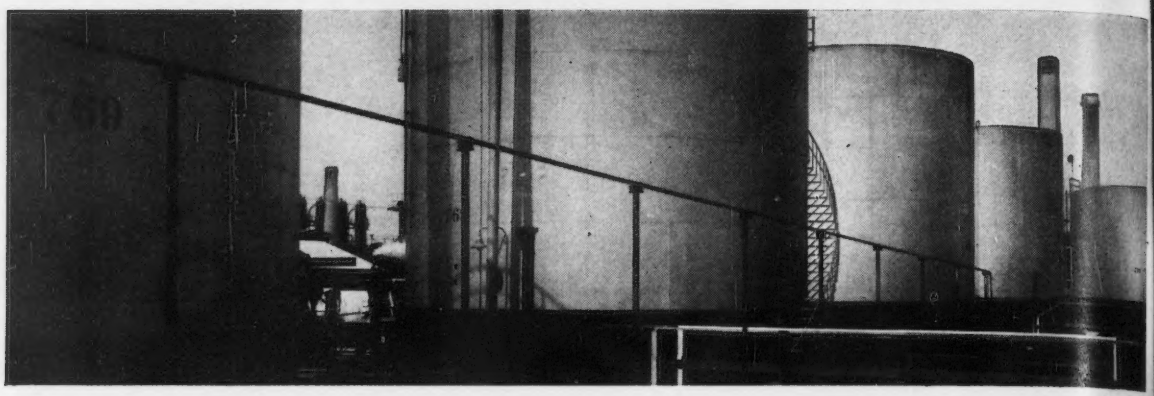

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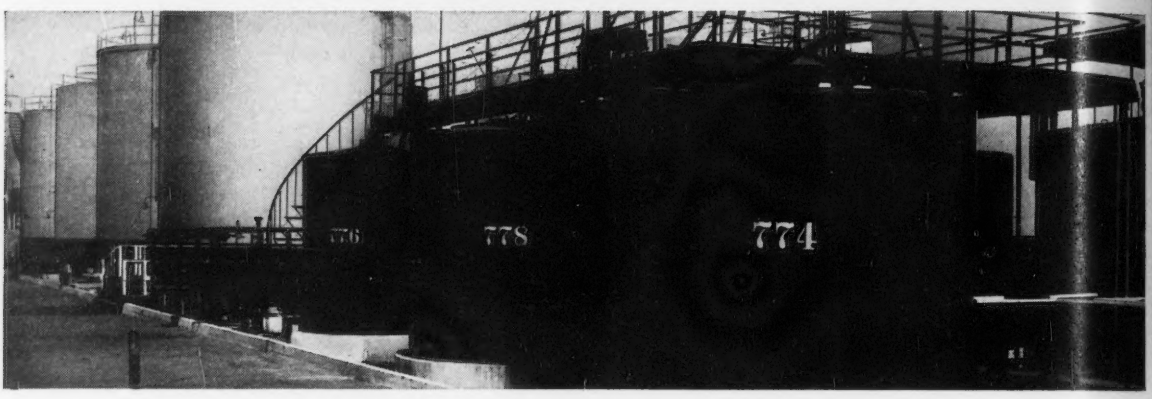

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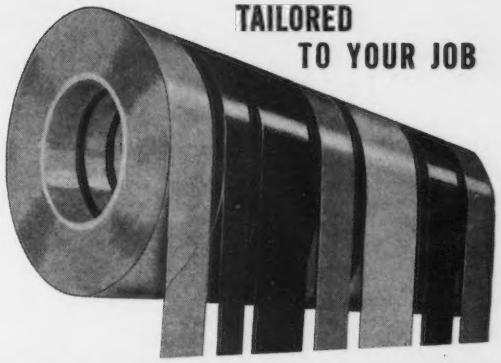

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(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

(f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.

(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

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Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 919 Milam Building, 803 Texas Avenue, Houston 2, Texas.

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Figure 1.

IMP

A Study of Some Metals for Use As Permanent Anodes In Water-Tank Cathodic Protection Systems ★

By A. L. KIMMEL

Theoretical

NUMEROUS TEXTS on electrochemistry describe in detail the anode process of metal solution in electrolytic cells. Briefly, electrons are removed from the anode metal molecules forming ions which go into solution in the electrolyte (Equation 1).

$$\text{Metal} - \text{electrons} = \text{Metals ions} \qquad (1$$

If conditions are such that the current flow produces electron removal only from the anode metal, then the rate of destruction of the anode will depend on the magnitude of the current, the time of current flow, and the equivalent weight of the metal. This is one statement of Faraday's Law.

Current flow through an electrolyte also tends to produce increased ionization (Equation 2).

$$2H_2O \xrightarrow{\text{current}} 2H^+ + 2OH^- \qquad (2$$

Furthermore, ions having a negative charge, when near the anode, may lose them and revert to their molecular state (Equation 3).

$$2\ OH^- - 2\ \text{electrons} \rightarrow H_2O + \tfrac{1}{2}\ O_2 \qquad (3$$

If the current effects at the anode are used wholly to convert ions to their molecular state, then no anode metal destruction will be encountered.[1] In that case the number of molecules liberated at the anode surface is a function of the time the current flows and it can be calculated from Faraday's Law. Whether or not the anode is destroyed will depend on the anode metal, the condition of the metal surface, and the electrolyte. This is well illustrated by the work of C. G. Fink.[1]

★A paper presented at the Sixth Annual Conference, National Association of Corrosion Engineers, St. Louis, Mo., April 4-7, 1950.

A. L. Kimmel—Assistant professor of chemical engineering at the University of Florida, is in charge of corrosion research for the Engineering and Industrial Station. He has devoted the past four years to water tank protection problems, fundamental studies of cathodic protection and general metal corrosion research. He holds degrees of B.Ch.E. and M.Ch.E. from University of Louisville, Ky., and was in charge of paint and varnish development for a Louisville paint company before coming to Florida.

Abstract

In the design of cathodic protection systems for water tanks, using an external source of direct current, it is necessary to select a metal from which the permanent anodes are to be fabricated. With the large number of metals and alloys now commercially available, the engineer has a wide selection and it is advisable that he have available data pertaining to the destruction rate of these metals at the approximate conditions of operation. According to Faraday's law, during electrolysis, a metal is destroyed in proportion to its equivalent weight, and the product of the time current flow. This relationship is true if the metal is pure, being electrolized in a solution of its ions, and polarization and other effects eliminated. In water tank cathodic protection systems, these conditions are never present. This paper presents corrosion data on a number of commercial metals and alloys used as permanent anodes. Investigations were made in water of pH 6.3 and 8.6; the latter having a higher alkaline earth content. The data are presented in both table and graphic form. Corrosion rate data are presented in pounds per unit current density per year. The current density range for each metal studied was from ¼ to 4 amps. per sq. ft.

The corrosion products formed on or near the anode surface are a result of chemical reactions between the available ions and are not current consuming. The quantity of the materials formed depends upon the current only to the extent of ion availability (Equation 4).

$$\text{Metal ion}^{++} + OH^- = \text{Metal Hydroxide} \quad (4$$

When studying anode corrosion in water-tank cathodic protection systems, it is usually found that a combination of the above processes takes place. Both metal destruction and molecule liberation occur simultaneously. Since the electrolyte is water, gaseous oxygen is the material liberated. It will be noted from Equation 5 that after oxygen liberation the hydrogen ions (H^+) remain in solution.

$$2H^+ + 2\,OH^- - 2 \text{ electrons} \rightarrow 2H^+ + H_2O + \tfrac{1}{2}O_2 \quad (5$$

Therefore, there is a lowering of the pH in the vicinity of the anode and it reaches a minimum value at the anode surface.[2] Metals above hydrogen in the electrochemical series can liberate hydrogen ions from a solution by direct replacement (Equation 6).

$$2H^+ + \text{metal} = H_2 + \text{Metal ion} \quad (6$$

This process will increase anode destruction, depending on the metal, and is not current-consuming. Liberated oxygen at the anode surface can further increase the destructive process by the formation of metal oxides with the anode metal (Equation 7).

$$\text{Metal} + O_2 = \text{Metal Oxide} \quad (7$$

If these oxide materials are granular and loosely adherent, anode losses are increased, while if they form a thin uniform film they may serve to reduce corrosion rates.

The effect of corrosion-product formation on the anode surface may be advantageous or not, depending on its physical nature. If the coating is adherent, and of low electrical conductivity, serious current flow limitation may result. On the other hand, if the materials formed are good conductors or loosely attached, only minor current limitation will be found. There are exceptions to both of these cases.

Alloys present a special case when corroded anodically in that the internal grain structure plays an important part. When the alloy is heterogeneous, local galvanic couples produce corrosion of one of the phases. This anode metal loss is in addition to that produced by the current flow. Homogenous alloys (austenitic) act as pure metals and, therefore, they will not be further discussed.

Commercial metals (pure and alloyed) are seldom free from inclusions and strains which aid their destruction in electrolytes. The inclusions are permanent and are not controllable by the corrosion engineer. Stresses and strains due to cold-working may be eliminated by proper heat treatment. Whether or not this is desirable will depend upon the over-all economy of the operation.

To summarize factors which tend to increase anode metal losses during electrolysis:

[1]The current density
[2]Replacement of hydrogen ions by the anode metal
[3]Oxide formation
[4]Galvanic effects

Factors which decrease anode metal losses are:

[1]Preferential gas formation
[2]Oxide formation (protective film type)

The rate of corrosion product formation does not affect the over-all anode corrosion rate and is usually listed as a side reaction. Its chief effect is to limit current flow by increasing the electrical resistance near and on the anode surface.

Experimental Procedure

The type of electrolytic cell used in this work is shown in Figure 1. These cells had an anode-to-cathode area of 1 to 8, in order to insure uniform current distribution over the anode surface. Strip anodes were used instead of round ones for the same reason.

Gainesville city tap water was used as the electrolyte. This water had a medium hardness, and a pH value of 8.6. For the low pH range, this same water was used with an addition of a small amount of hydrochloric acid. In all cases the liquid volume in the cell was 1000 cc and was changed three times each 24 hours.

Anodes were made from strips of metal ½-inch by 4 inches cut from 20-gauge stock. The total submerged area was two square inches. All samples were cleaned with steel wool, washed in benzol, then in alcohol and finally dried to constant weight at 110°C. After testing, all samples except aluminum were cleaned and treated in the same manner. In the case of aluminum, the samples were cleaned by the method described by McKee and Brown.[3] This replaced the steel wool cleaning method; the washing and drying operations remained the same.

Current time data were obtained by means of a recording Bristol milliammeter. This instrument also served to indicate current limiting characteristics of the anode metals as well as to establish average current densities for the test period.

Current density and weight loss data are reported on a basis of one square foot of anode. Weight loss data (corrosion rates) are listed for a one year period.

Data and Results

Observations of the anode corrosion process during the experiments indicated that, in all cases, gassing occurred at the electrodes. This indicated that free oxygen molecules and hydrogen ions were available at the anode surface and could take part in the destructive process.

The anode metal was examined by microscopic methods for inclusions, wide grain boundaries and different phases. This examination served to indicate the susceptibility of the metals to local or galvanic action. Comments on these factors will be found listed with the metal.

Complete quantitative data on the increase of anode-to-solution resistance was not available and the comments are made from observations of the current time curves.

Aluminum (99.99%) Anodes

The aluminum used in this series of tests was a special non-commercial grade and is the purest metal of the series. Microscopic examination showed practically no grain boundaries even at high power. In the annealed condition the metal was almost as soft as lead, so fabrication of anodes and installation required careful handling.

Anode corrosion data are presented in Table I and Figure 2. Annealing and pH range used showed little effect on the corrosion rates. In all tests, corrosion rates were higher than those predicted by Faraday's Law. Anode resistance rapidly increased after the test was started and water turbulence did little to restore it to its initial value. Anode resistance increase was about 300 percent.

Aluminum 3 S Anodes:

Aluminum 3 S is a commercially available alloy containing 0.2 percent Cu, 0.60 percent Si, 0.7 percent Fe, 1—1.5 percent Mn, and 0.1 percent Zn, the remainder being aluminum.[4] The alloy is harder and stronger than the pure metal and is available in rods and sheets. The alloy softens to some extent on heat treatment but still could be handled for fabrication and installation.

Anode corrosion rates were lower for the annealed alloy than when it was in the cold rolled state, but both were higher than the theoretical. The pH range used in the tests showed little effect on either condition as shown by Table II and Figure 3. Increased anode-to-solution resistance was pronounced, being in the order of 300 percent and was little affected by water turbulence. The corrosion product was very adherent and the electrode during operation was surrounded by a slime of aluminum hydroxide. Due to the large deviation from the Faraday Law curve, the hard granular oxide film on the anode surface and gassing at the anode it is probable that galvanic effects, oxidation and hydrogen replacement supplement the destructive effects of the current flow.

Black Iron (Hot Rolled):

The commercial hot rolled black iron used in these tests had a carbon content of 0.07 percent and microscopic examination showed it to contain inclusions. No heat treatment was used as the added cost usually would not be justified.

Anode corrosion was affected by changes in pH of solution as shown by Figure 4 and Table III. Faraday Law curves were plotted for both a valence of 2 and 3, since oxidizing conditions prevail at the anode, and future studies should include an analysis of the corrosion product. Corrosion rates were

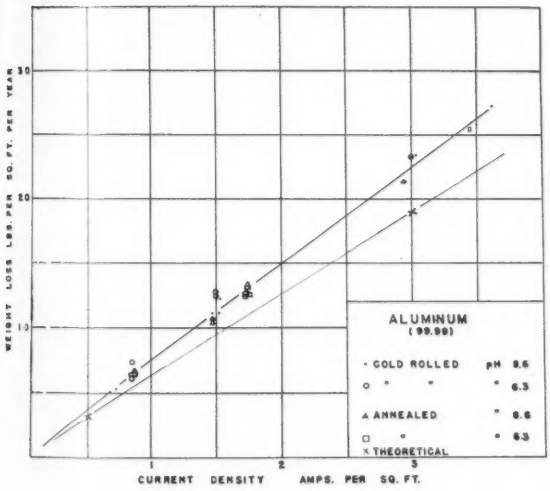

Figure 2.

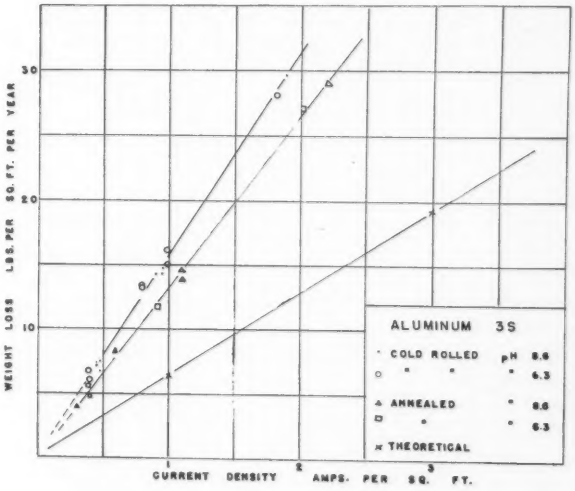

Figure 3.

TABLE I—Aluminum (99.99%)

	COLD ROLLED			ANNEALED		
	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
Water pH 8.6	1	0.74	5.38	13	0.87	6.13
	2	0.74	5.30	14	0.87	6.74
	3	1.48	11.10	15	1.47	10.90
	4	1.51	12.30	16	1.47	10.50
	5	1.51	11.10	17	1.74	13.01
	6	3.03	23.40	18	2.94	21.40
Water pH 6.3	7	0.85	6.17	19	0.85	6.50
	8	0.85	6.25	20	0.85	6.37
	9	1.50	12.61	21	1.71	12.80
	10	1.50	12.60	22	1.73	13.10
	11	1.71	12.70	23	1.73	12.40
	12	3.00	23.20	24	3.46	25.40

TABLE II—Aluminum 3 S

	COLD ROLLED			ANNEALED		
	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
Water pH 8.6	1	0.45	7.42	13	0.29	4.02
	2	0.45	7.40	14	0.58	8.30
	3	0.90	14.30	15	1.00	14.61
	4	0.94	14.80	16	1.10	13.82
	5	0.94	14.50	17	2.20	29.11
	6	1.89	29.78	..	....	....
Water pH 6.3	7	0.40	6.10	18	0.39	5.52
	8	0.40	6.80	19	0.40	4.95
	9	0.79	13.24	20	0.910	11.75
	10	0.99	15.00	21	2.02	27.13
	11	0.99	16.21	..	....	....
	12	1.83	28.10	..	....	....

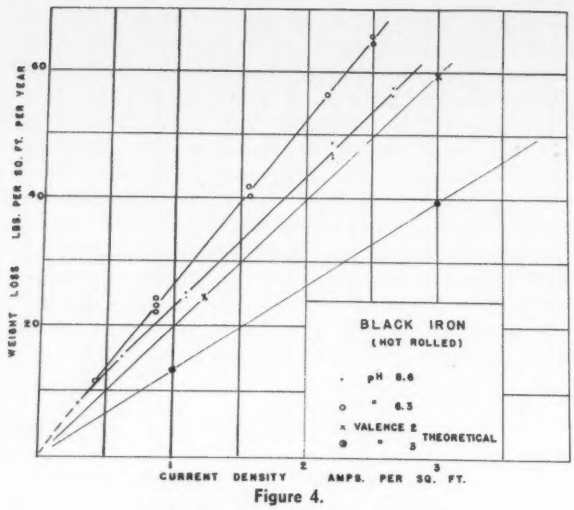

Figure 4.

TABLE III—Black Iron (Hot Rolled)

WATER pH 8.6			WATER pH 6.3		
Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
1	0.29	8.00	10	0.42	11.30
2	0.62	15.10	11	0.87	22.00
3	1.09	24.40	12	0.87	23.00
4	1.09	25.10	13	0.87	24.20
5	2.20	46.20	14	1.56	41.80
6	2.20	46.80	15	1.58	40.20
7	2.20	48.70	16	2.15	56.40
8	2.66	56.00	17	2.49	65.50
9	2.66	57.50	18	2.50	64.40

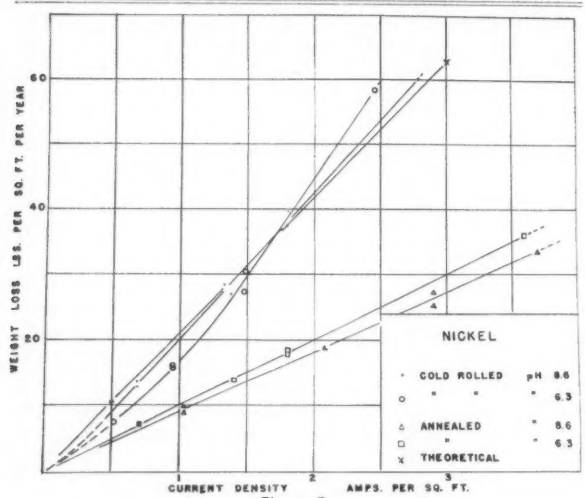

Figure 5.

TABLE IV—Nickel (Commercial)

	COLD ROLLED			ANNEALED		
	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
Water pH 8.6	1	0.69	12.80	13	1.04	9.00
	2	0.69	13.70	14	1.04	9.80
	3	1.32	28.20	15	2.08	18.80
	4	1.39	26.50	16	2.90	25.20
	5	1.80	39.90	17	2.90	27.20
	6	2.79	58.20	18	3.70	33.50
Water pH 6.3	7	0.520	7.50	19	0.70	7.15
	8	0.900	14.90	20	0.70	7.16
	9	0.900	15.10	21	1.40	13.90
	10	1.480	27.50	22	1.80	18.00
	11	1.480	30.50	23	1.80	18.50
	12	2.450	58.40	24	3.60	36.00

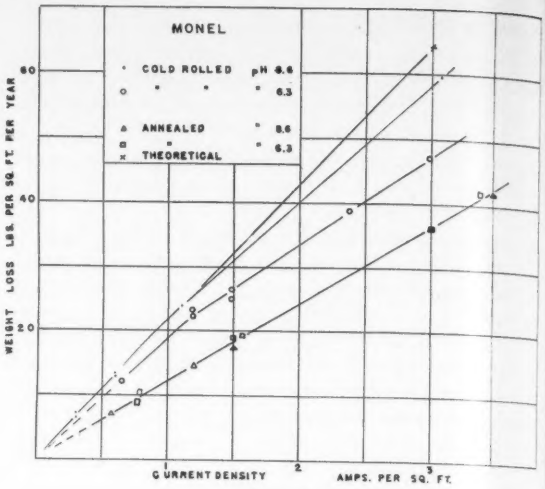

Figure 6.

TABLE V—Monel

	COLD ROLLED			ANNEALED		
	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
Water pH 8.6	1	0.30	7.11	13	0.58	7.10
	2	0.61	13.20	14	1.20	14.50
	3	1.22	24.00	15	1.20	14.51
	4	1.59	33.80	16	1.50	17.20
	5	1.59	31.10	17	3.00	36.00
	6	3.18	59.70	18	3.50	40.80
Water pH 6.3	7	0.65	12.00	19	0.77	8.80
	8	1.19	23.40	20	0.77	10.05
	9	1.48	24.90	21	1.50	18.80
	10	1.48	26.50	22	1.56	19.20
	11	2.38	38.80	23	3.00	36.00
	12	2.96	47.30	24	3.40	40.80

higher in both cases than those predicted by the two theoretical curves. The theoretical curve based on a valence of 2 shows the better agreement. Anode surfaces showed little collection of corrosion product and anode-to-solution resistance changed very little.

Nickel (Commercial):

The nickel used in these tests was of commercial cold rolled stock. Microscopic examination showed narrow grain boundaries and no appreciable amount of inclusions. Annealing was as specified by International Nickel Company in their *Nickel and Nickel Alloys* handbook.[5]

Anode corrosion data are given in Table IV and Figure 5. Cold rolled nickel anodes showed lower corrosion rates than the theoretical values at current densities between zero and 1.75 amp./sq. ft. Above this value the rates were greater than those predicted. At the low pH value corrosion rates varied above and below those at the high pH and for the high and low current densities specified above. Annealing produced a straight line variation of corrosion rate with current density and less corrosion at the low pH value. At both pH of 8.6 and 6.3 annealed nickel anodes showed less initial loss than predicted by the Faraday Law curve. Anode oxidation took place as was indicated by the hard black coating on its surface. Other corrosion products were formed but were removed

by water turbulence. Anode-to-solution resistance showed a small increase, in the order of 15 percent.

Monel Anodes:

The Monel metal anodes were made from commercial cold-rolled sheets. The annealed anodes were prepared from the same material by heat treatment as recommended by the International Nickel Company.[5] The Faraday Law curve was prepared by using the pseudo equivalent weight as calculated from the composition.

Anode corrosion rate data are shown in Table V and Figure 6. Corrosion rates in all cases proved to be less than those predicted by the theoretical curve. For the unannealed specimens, pH showed a definite effect on the corrosion rate while in the annealed state, no difference was apparent and the corrosion rate was less. The monel anodes showed, in all cases, deep pitting. This was rather evenly distributed over the entire exposed surface. The corrosion product was soft and easily removed with water turbulence. Anode-to-solution resistance did not change appreciably during the test.

Inconel Anodes:

The Inconel anodes were made from commercial cold-rolled sheet stock and annealed specimens prepared by approved heat treatment methods. (*Nickel and Nickel Alloys* handbook).[5] Faraday's Law curve was obtained from the apparent equivalent weight calculated from the alloy composition.

Corrosion rate data for Inconel anodes is given in Table VI and Figure 7. As illustrated, all tests showed corrosion rates less than the predicted values. The solution pH value affected the corrosion rates only on the unannealed specimens, while in the annealed state little difference from this factor was noticed. Anodes acquired a thin film of brown material which was very adherent. Other products of corrosion which collected around the anode were easily removed during the water-changing. Anode-to-water resistance increased about 50 percent during the tests.

Stainless Steel (302) Anodes:

The anodes for this test were cut from commercial stock that had a surface equivalent to the ground commercial rod stock. Annealing was done as specified by the U. S. Steel Corp.[6] and the surface was then returned to the original condition with emery paper. Faraday's Law curve was based on the pseudo equivalent weight of the alloy.

The solution pH showed little effect on the corrosion rate of the stainless steel anodes as shown in Table VII and Figure 8. Since the corrosion rates were small and somewhat erratic, maximum values only were used in plotting the curves. Annealing definitely improved the corrosion resistance. Corrosion

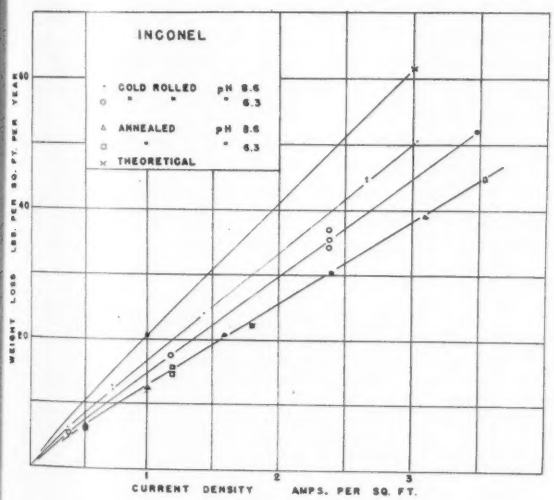

Figure 7.

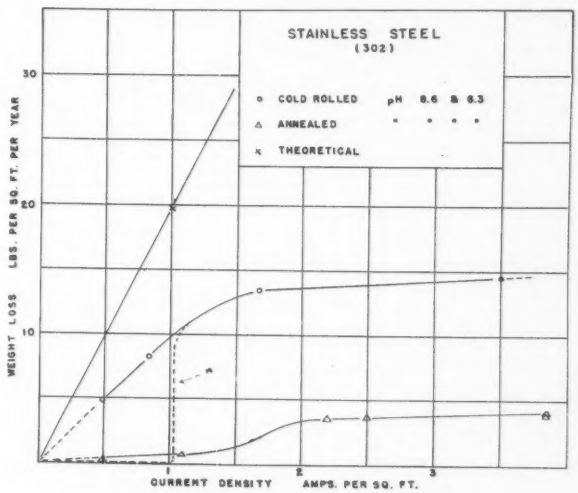
STAINLESS STEEL (302)
COLD ROLLED pH 8.6 & 6.3
ANNEALED
THEORETICAL
WEIGHT LOSS LBS. PER SQ. FT. PER YEAR
CURRENT DENSITY AMPS. PER SQ. FT.

Figure 8.

TABLE VI—Inconel

COLD ROLLED			ANNEALED		
Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
1	0.36	6.08	13	0.50	6.70
2	0.72	12.90	14	1.00	12.80
3	0.72	10.30	15	1.60	20.90
4	1.44	24.20	16	1.60	20.40
5	2.66	44.80	17	3.20	39.20
6	3.03	50.40	18	3.20	39.00
7	0.36	5.50	19	0.50	6.20
8	1.19	17.80	20	1.20	14.80
9	2.39	34.70	21	1.20	16.00
10	2.39	35.50	22	1.80	22.50
11	2.39	37.10	23	2.40	30.48
12	3.48	52.20	24	3.55	45.00

TABLE VII—Stainless Steel (Type 302)

	COLD ROLLED			ANNEALED		
	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
Water pH 8.6	1	0.49	4.90	13	0.50	0.00
	2	0.49	4.00	14	0.50	0.40
	3	0.85	7.60	15	1.10	0.80
	4	0.85	7.60	16	2.20	3.50
	5	1.67	13.40	17	2.50	3.60
	6	3.50	14.10	18	3.85	3.90
Water pH 6.3	7	0.50	4.80	19	0.50	0.21
	8	0.50	3.20	20	0.50	0.38
	9	0.85	8.20	21	1.00	0.70
	10	0.85	8.10	22	2.00	3.05
	11	1.65	13.20	23	2.30	3.50
	12	3.48	14.50	24	3.85	4.10

rates in both cases were well below those predicted. This is probably due to the fact that stainless steels have good corrosion resistance in oxidizing solutions. No corrosion product was noted on the anode surface.

The dotted curve designated with the (*) was prepared from previous unpublished data obtained by the author using highly polished stainless steel rods (Type 302). These showed practically no corrosion at current densities below 1 amp./sq. ft. and a rapid increase above this value.

Stainless Steel Anodes (316):

The anodes were prepared from commercial stock with a surface similar to the commercial ground rod. Annealing was done as specified by the U. S. Steel Corp.[6] and the surface was then put in its original condition with emery paper. The theoretical curve was obtained from the pseudo equivalent weight of the alloy.

Corrosion rate data are given in Table VIII and Figure 9. In both cases, the pH values used showed little effect on the specimens. Annealing did improve the anodic corrosion resistance; however, they were somewhat higher than the Type 302 previously recorded. The corrosion rates were less than the predicted values. Corrosion products were absent and only a small increase in anode-to-solution resistance was noted. The latter was probably due to gassing.

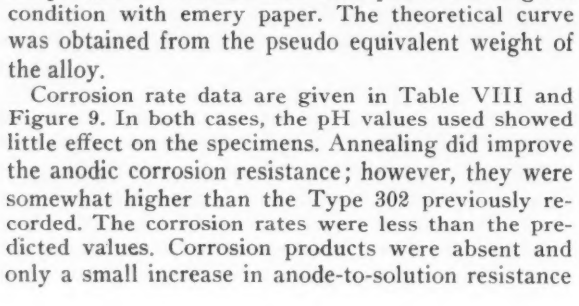

Figure 9.

TABLE VIII—Stainless Steel (Type 316)

	COLD ROLLED			ANNEALED		
	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.	Sample No.	Current Density A/Sq. Ft.	Weight Loss Lbs./Sq. Ft./Yr.
Water pH 8.6	1	0.24	5.00	13	0.55	3.80
	2	0.24	2.18	14	0.55	0.90
	3	1.10	10.15	15	1.10	6.51
	4	2.20	15.00	16	2.50	15.80
	5	2.20	6.10	17	2.50	10.10
	6	3.98	27.00	18	4.00	16.50
Water pH 6.3	7	0.24	4.92	19	0.55	3.70
	8	0.24	1.66	20	0.55	1.62
	9	1.00	10.00	21	1.10	3.20
	10	1.00	6.20	22	2.20	14.00
	11	2.30	14.20	23	2.20	6.67
	12	2.30	8.15	24	4.00	16.30

Conclusions

All the metals selected in this study have been, or can be, used as anodes for water-tank cathodic protection systems. For metals and alloys which develop high water-to-anode resistance (aluminum, etc.), a rectifier with a wide voltage range should be specified to maintain proper cathode current density.

From a study of the anodic corrosion conditions, the stainless steels, of the 18-8 variety, seem to be most suitable. They are most resistant to corrosion at oxidizing conditions and the data presented indicate good life periods. When using stainless steel for anodes, the metal surface finish should be as smooth as economically possible.

On the basis of weight, aluminum is the most inexpensive and is used successfully to a large extent. These anodes do require more frequent replacement and the increased cost of the suitable rectifier unit should be included in the over-all economy.

In water-tank cathodic protection systems, ordinary iron anodes show a high corrosion rate (Figure 4) and would have to be replaced often. Rusty water (red water) which is objectionable in most cases would result from the large amount of corrosion product. They are seldom if ever used in water-tank protection systems.

The nickel, Inconel and Monel act similarly to one another when used in water-tank protection systems and their corrosion resistance, when used as anodes, decreases in the order in which they are named. The data indicate that annealing should be used for best results when using these metals.

In considering these conclusions, allowance should be made for the fact that they are the results of laboratory studies and will probably show some deviation from field installations. Pilot plant or field data were not available for comparison purposes.

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2. A. L. Kimmel, Special Anodes for the Cathodic Protection of Water Tanks. *Corrosion*, **5**, No. 7 (1949) July.
3. McKee & Brown, Resistance of Aluminum to Corrosion in Solutions Containing Various Anions and Cations. *Corrosion*, **3**, No. 12 (1947) Dec.
4. Alcoa Aluminum and Its Alloys, Aluminum Co. of America (1947).
5. Nickel and Nickel Alloys, International Nickel Co.
6. The Fabrication of U. S. S. Stainless and Heat Resisting Steels, Carnegie-Illinois Steel Corp., Revised Edition (1946).

DISCUSSION

Comment by L. P. Sudrabin, Electro Rust-Proofing Corp. (N. J.), Newark, N. J.

Since the gases and other anodic product produced at an anode may have secondary effects on the corrosion problem, consideration should be given to these. The gases evolved at sacrificial anodes (aluminum) are almost entirely hydrogen, whereas the gases evolved at non-sacrificial anodes (platinum, stainless steel exhibiting passive properties, etc.) are O_2 Cl_2 depending on the solution.

Our studies have shown that stainless steel (in-

cluding 302 annealed) lose their passive properties when used as anodes in waters containing sizable amounts of Cl^-. Annealed 302 exhibited passive properties in Belleville, N. J. water at c.d.'s up to 500 ma/sq. ft. This alloy is consumed at near the electrochemical rate when 25 ppm NaCl has been added to Belleville water which normally contains 6-8 ppm Cl^-.

Stainless steel anodes of various types have been installed in over 500 tanks. At the present time only eight tanks have the original anodes. In each of the eight tanks the water stored has less than 15 ppm Cl^-.

It is felt that in any discussion concerning anodic or cathodic behavior in aqueous media the analysis should be used to define the conditions of the study.

In the selection of anodes for use in water storage tanks, consideration should be given to the nature of the gas involved and/or other products produced at the anode. The anodic products depending on their nature can create either harmful or beneficial effects upon the over-all corrosion problem.

We have observed that the gas evolved from 17-ST-4 aluminum anodes in Belleville, New Jersey, tap water is nearly pure hydrogen at anode current densities of 400 milliamperes per square foot which corresponds to a value frequently met in practice. The amount of hydrogen evolved increases with increases in the anode current density. The gas evolved in Belleville, N. J. water from platinum, graphite and stainless steels which exhibit passive properties produce oxygen gas electrochemically equivalent to the anode current. In waters with higher chloride concentrations chlorine gas is evolved.

Belleville, N. J., Water Analysis

pH	7.0
	PPM
Total dissolved solids	49
Total hardness	41
Total alkalinity	14
Chloride	4
SO_4	10
Ca	12
Mg	3

We have noted that stainless steels (including 302 annealed) lose their passive properties when used as anodes in waters containing sizeable amounts of chloride ion. At anode current densities of 500 milliamperes per square foot annealed 302 exhibited passive properties in Belleville water. However, this alloy was consumed at near the electrochemical equivalent rate when 25 p.p.m. of NaCl has been added to the water.

We have used various types of stainless steels in over 500 water tanks. At present only some 8 or 10 of the tanks have the original anodes. In each of these tanks the water stored has less than 15 p.p.m. of chloride ion.

It is felt that a complete analysis of the water used in Professor Kimmel's study will add greatly to his very excellent paper.

Author's Reply:

The remarks of Mr. Sudrabin are very pertinent to the problem of permanent anode corrosion. I fully agree that the gas liberated at the anode surface is important as it will indicate to some extent the mechanism of anode metal loss.

In the case of aluminum two reactions definitely take place and a third will if chlorine is present. Liberated oxygen forms aluminum oxide and hydrogen ions are replaced in the solution near the anode by the aluminum, thus the evolved gas is largely hydrogen. If chlorine is present the liberated chlorine or chloride ion will probably be used up to a large extent in the formation of aluminum chloride.

In the case of stainless steel the hydrogen replacement reaction may be eliminated and the liberated oxygen tends to produce a passive surface. I have found that excessive chloride concentrations (around 40 ppm) will activate stainless steel anodes and will produce corrosion rates approaching calculated values. This is in reasonable agreement with Mr. Sudrabin's findings.

The following is an analysis of the Gainesville water used in the experiments.

	ppm
Hardness	63
Chloride	2.9
Chlorine (residual)	.4
SO_4	43
Ca	17
Mg	3.6
*pH	8.6

*For the low pH range the value was lowered to 6.3 by the use of HCl.

From the results of this investigation I feel that further studies should include a more thorough study of the anode corrosion products.

Design of Anode Systems for Cathodic Protection Of Underground and Water Submerged Metallic Structures*

By E. R. SHEPARD and HENRY J. GRAESER, JR.

A. Underground Structures

1. *Introduction*

THE STUDIES on ground beds and anode configurations here reported were undertaken by the authors as members of the Scale and Corrosion Committee of the Chief of Engineers' Office. This committee, composed of technical personnel in the utilities field, includes among its membership representatives of the Army, Navy, and Air Force and is engaged in the study of all corrosion problems arising from the operation and maintenance of Armed Services field installations.

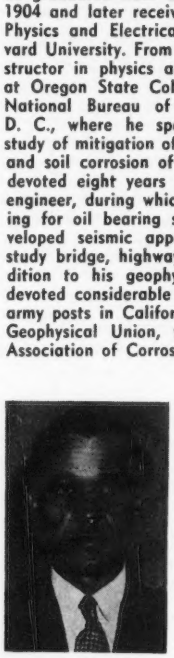
Recent acute soil corrosion problems at some Army installations in the Southwest and Western Areas focused the attention of the committee on the potentialities of cathodic protection. While the literature offered voluminous information on experiences in the field of long pipe line protection, there was need for simple and easily applied design criteria applicable to cathodic protection of gas and water distribution systems intermixed, and also large water storage tanks. In all such installations the design and construction of the anodes or ground beds is of prime importance as the voltage required, and therefore the power consumption, is determined almost entirely by the resistance of the anode to ground, because of its limited area, and only slightly by the resistance of the relatively large protected structure, hereafter termed the cathode. It is important, therefore, that some thought and attention be given to the physical dimensions and geometric arrangement of the anode units as well as to their general location with respect to the cathode and to the character of the soil or other medium in which they are installed.

In the practical application of cathodic protection to piping systems, anodes of various forms and dimensions are in common use, including multiple driven pipes or rods, pipes buried longitudinally, iron masses such as large fly wheels, old engines and worn-out machinery, and carbon or graphite rods installed either vertically or horizontally in various geometric arrangements. Recently the authors had the opportunity of conducting a number of laboratory tests in tanks and vessels of various dimensions at the National Bureau of Standards, with the purpose of determining the resistance of some of these configurations not readily susceptible to mathematical analyses, and of developing constants by which mathematical computations could be eliminated or simplified. This opportunity afforded the Scale and Corrosion Committee through the facilities of the Underground Corrosion Section of the Bureau, and the cooperation and counsel of its staff, made possible the collection of the data here presented on this subject.

In designing or analyzing ground beds or anodes for the protection of underground structures, it is customary to refer to the resistance of the anode to *ground* or to *remote ground*. Just what these terms signify is somewhat indefinite. In practice the cathode to which discharge takes place is usually a long pipe line or a network of underground pipes. As to just what portion of the medium between the two electrodes should be considered as anode resistance and what portion as cathode resistance is obviously a question to which no definite answer can be given. The actual potential gradient in the medium between the anode and cathode usually will be something like that shown in Figure 1. It will be steep adjacent to the anode because of its relatively small size, and will flatten out to a small

★A paper presented at the Sixth Annual Conference, National Association of Corrosion Engineers, St. Louis, Mo., April 4-7, 1950.

E. R. SHEPARD—Recently retired from the Corps of Engineers, U. S. Army, where he had been employed since 1938 in the development and maintenance of seismic apparatus and training field personnel for sub-surface exploration of dam and reservoir sites. Born in Utah, he graduated from University of California in 1904 and later received a Master's Degree in Physics and Electrical Engineering from Harvard University. From 1909 to 1914 he was instructor in physics and electrical engineering at Oregon State College. In 1941 he joined National Bureau of Standards, Washington, D. C., where he spent eleven years in the study of mitigation of stray current electrolysis and soil corrosion of underground piping and cable systems. He also devoted eight years to similar and related problems as a consulting engineer, during which period he spent some time in seismic prospecting for oil bearing structures in Texas. From 1933 to 1938 he developed seismic apparatus for the Public Roads Administration to study bridge, highway and engineering structures' foundations. In addition to his geophysical studies Mr. Shepard during recent years devoted considerable time to cathodic protection of piping systems in army posts in California and Texas. He is a member of the American Geophysical Union, the Washington Philosophical Society, National Association of Corrosion Engineers and the Sigma Xi Society.



HENRY J. GRAESER—Now Assistant Superintendent of the Department of Waterworks, City of Dallas, Texas, Mr. Graser's principal field of activity has been management of operation and maintenance of water supply and sewerage utility systems. He holds a degree of BS in Engineering Administration, Texas Agricultural and Mechanical College, College Station, Texas.

Abstract

Studies on ground beds and anode configurations were undertaken by the authors as members of the Scale and Corrosion Committee of the Chief of Engineers Office. Acute soil corrosion problems at some Army installations in Southwestern and Western areas led the Committee to the consideration of cathodic protection. Previous design criteria showed that the voltage required, and therefore the power consumption, is determined almost entirely by the resistance of the anode because of its limited area. Study was made of a number of different anodes of various dimensions and geometric shapes installed both vertically and horizontally. A brief analysis of the potential gradient in the medium between the anode and the cathode is presented. Equations are developed for the resistance of a hemisphere to remote ground and for the resistance of a vertical rod to ground. Calculated resistances obtained by using the equation developed for a vertical rod are compared in tabular form with those obtained by using the equation developed for a vertical rod are compared in tabular form with those obtained by using Dwight's and Peters' equations as well as measured values using an AC Bridge. Studies were also made on the resistance to remote ground of a limited length horizontal pipe which may be used as an anode. The effect of the ground surface on the resistance of horizontal conductors were studied in experiments carried out in a slate tank having the two rear sides of the tank lined with thin sheet iron. A ¼" steel rod which was exactly the length of the tank was supported horizontally midway between the side walls. Resistance measurements were made between the electrodes and the walls of the tank by the means of a Wheatstone Bridge and an AC galvanometer. The McCollum Earth Current Meter, developed by the National Bureau of Standards in 1927 was used for studying stray current electrolysis on an underground piping system. Experiments indicate that the measurement of soil resistivity may best be determined by using the four electrode method. An equation is given for the determination of a specific resistivity in homogeneous soil from the current and voltage readings obtained from this test. A typical design problem for the cathodic protection of pipe lines using rectifiers and graphite anodes is presented. Factors affecting required current density in the design of cathodic protection installations in large water tanks are discussed.

value before assuming the pipe potential. Although the gradient continues to decline, irrespective of the distance between the anode and cathode, we may select som point, such as P, well below the knee of the curve, where the gradient is small, and designate it as *ground* or *remote ground*. This is, of course, still indefinite but it will be shown that the gradient curve is logarithmic in character and in practice soon assumes a near horizontal slope, so that if the distance to it is large compared to the dimensions of the anode the term *ground* or *remote ground* becomes a fairly well established conception. Specific instances to follow will further illustrate the significance of these terms.

2. *Resistance of a Hemisphere to Remote Ground*

In analyzing the resistance to ground of some physical bodies it is necessary to resort to simple calculus and also to employ the fundamental formula for the resistance of a conductor,

$$R = \frac{\rho L}{A}, \qquad \text{(Eq. 1}$$

where ρ is the specific resistivity of the material; L, the length of the circuit, and A, the sectional area.

Consider now a hemisphere of radius "a" embedded in an infinite medium of specific resistivity ρ, as shown

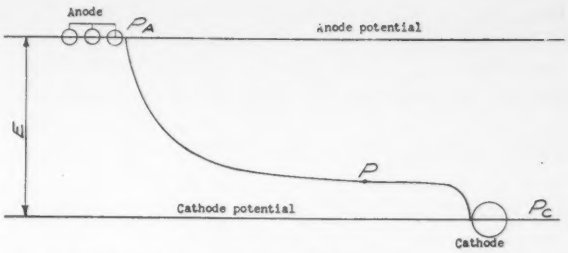


Figure 1—Potential gradient in earth between anode and cathode.

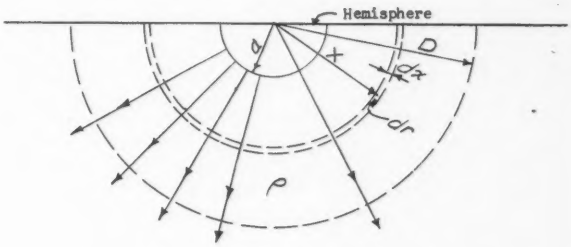


Figure 2—Resistance of a hemisphere to ground.

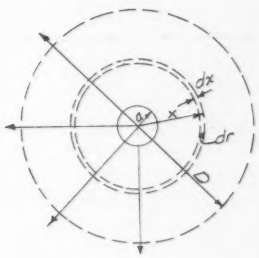


Figure 3—Resistance of a vertical rod to ground.

in Figure 2. The resistance to radial flow of current through the differential element dx will be, as in Eq. 1.

$$dr = \rho \frac{dx}{2\pi x^2}$$

The resistance R_D to a radial flow of current from the surface of the hemisphere to a distance D is found by integrating the above expression between the limits D and a. Therefore

$$R_D = \frac{\rho}{2\pi}\int_a^D \frac{dx}{x^2} = -\frac{\rho}{2\pi}\left(\frac{1}{D} - \frac{1}{a}\right) = \frac{\rho}{2\pi}\left(\frac{1}{a} - \frac{1}{D}\right)$$

By making D $\propto$ the expression becomes $R = \frac{\rho}{2\pi a}$ (Eq. 2

This means that the resistance of a hemisphere to remote or infinite ground is a finite or definite quantity, a most interesting fact, as it differs in this respect from a long cylinder, which will now be considered.

3. *Resistance of a Vertical Rod to Ground*

In Figure 3 let us assume a vertical rod of radius a and of great or infinite length, L, in an infinite medium of specific resistivity ρ. The resistance to radial flow of current from a 1 cm. length of the rod

through the differential element dx will be, as in Eq. 1.

$dr = \rho \frac{dx}{2\pi x}$. The resistance from the surface of the rod to a distance D is obtained by integrating the above equation between the limits D, and a, the outside radius of the pipe, to give

$$R_D = \frac{\rho}{2\pi}\int_a^D \frac{dx}{x} = \frac{\rho}{2\pi} \log_e \frac{D}{a}$$

Converting to practical units, the resistance of 1 ft. of rod to the radial flow of current is now $\frac{2.303\,\rho}{2\pi\ 30.48} \log_{10}\frac{D}{a}$, or R, the resistance of the entire rod to the

$$\text{radial flow of current} = \frac{0.012\,\rho\ \text{Log}_{10}\ \frac{D}{a}}{L} \qquad \text{(Eq. 3}$$

In Eq. 3, ρ is in ohm-cms., L in ft., and D and a must be in the same units, as they appear only as a ratio.

Figure 4 shows the manner in which the resistance of such a rod varies with the ratio of distance to radius of the rod. The graph is a logarithmic curve, the ordinates being simply the logarithus to the base 10 of the abscisae, D/a. While the resistance values continue to increase with the distance to remote ground, it is seen that the rate of increase is relatively small for values of D/a in excess of 300 to 500. For practical purposes we may therefore assume that *remote ground* exists at the distance where log D/a in Eq. 3 approaches the value 3. To be specific, let us take D/a at 500 for which log D/a is 2.7 and we will be very nearly right in computing the resistance of a long rod or pipe to remote ground. On this basis we can still further simplify Eq. 3 by substituting the value 2.7 for log D/a, and our equation then becomes

$$R = \frac{0.0324\,\rho}{L} \qquad \text{(Eq. 4}$$

As Eq. 3 is based on a strictly radial flow of current from the rod, it is not applicable to short rods in which fringing of the current stream lines from

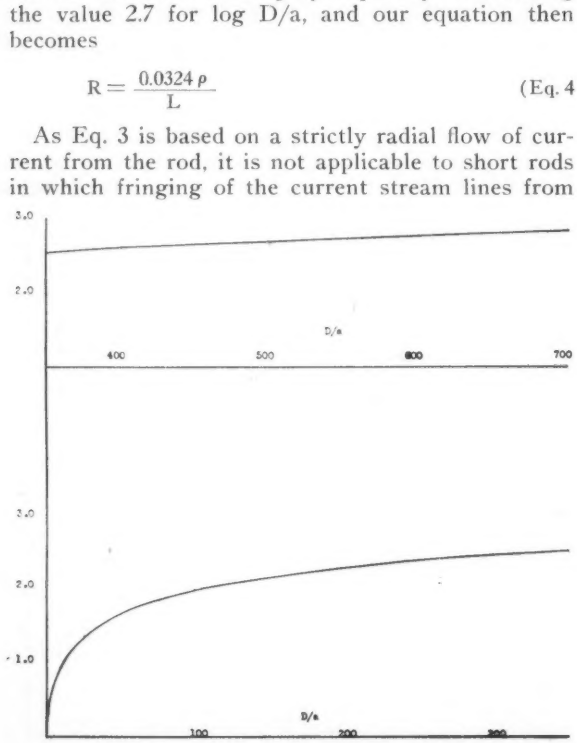


Figure 4—Increase in resistance of vertical ground rod of radius a with distance D from rod.

the lower end may introduce a considerable error. The classical method of calculating the resistance of ground rods is discussed by Dwight,[1] Peters,[2] and others. It is derived from the combined electrostatic capacity in free space of an electrode and its image above the surface of the ground. Dwight gives a convergent endless expression for the resistance of a cylinder whose length is great as compared to its diameter and reduces it to the following practical working equation which is said to be accurate within one percent.

$$R = \frac{\rho}{2\pi L}\left(\log_e \frac{4L}{a} - 1\right) \qquad \text{(Eq. 5}$$

Here L is the length of the rod and a, its radius, both in centimeters. Peters, failing to find a suitable expression for the capacitance of a cylinder and its image, uses that for an ellipsoid of revolution, from which the following expression for the resistance of a ground rod is derived.

$$R = \frac{\frac{2L}{\log_e \frac{a}{\pi L}}}{\pi L} \qquad \frac{\frac{2L}{\log_e \frac{a}{\pi l}}}{\pi l}$$

In Peters'[2] equation at the bottom of page 67, Tech. Paper 108, to which reference has been made, it should be noted that L is twice the length of the rod. Simplifying the above expression further we have:

$$R = \frac{0.012\,\rho \log_{10} \frac{2L}{a}}{L} \qquad \text{Eq. 6}$$

where L is the *length* of the rod in feet and a the radius. In the numerator L and a must be in the same units. Dwight also gives this equation but says that the error is greater than that in Eq. 5.

An interesting feature of Equations 5 and 6 is that they give finite values for R. Also the quantity D, occurring in Eq. 3, does not appear in these classical equations.

To check the accuracy of these equations, and also to determine to what lengths of rods Eq. 3 is applicable, resistance measurements were made between a ¼" steel rod and the wall of an 8-foot steel tank, 5 feet deep. See Table I.

TABLE I

Resistance of Vertical ¼" Steel Rod in 8-Foot Tank 5 Feet Deep. $\rho = 990$ ohm cm.

DEPTH OF ROD		By AC Bridge, ohms	Eq. 3 for Long Rods	Eq. 5 Dwight	Eq. 6 Peters
In Inches	In Diam.				
0.5	2	225.7	.....	212	260
1.0	4	151.0	.....	148	172
1.5	6	116	.....	115	131
2	8	98	.....	94.7	107.5
3	12	73	123	.....	80.0
4	16	59.6	92.3	57.7	64.5
5	20	50.8	73.9	73.9	54.5
6	24	44.5	61.5	42.5	47.1
7	28	39.7	52.7	.....	41.9
8	32	36.0	46.1	34.0	37.7
9	36	32.9	41.0	.....	35.2
10	40	30.4	36.9	28.6	31.5
11	44	28.1	33.5	.....	29.2
12	48	26.35	30.8	24.7	27.2
14	56	23.4	26.4	.....	24.0
16	64	21.1	23.0	19.6	21.5
18	72	19.2	20.5	.....	19.4
20	80	17.6	18.4	16.4	17.9
22	88	16.35	16.8	.....	16.6
24	96	15.25	15.4	.....	15.4
26	104	14.25	14.2	.....	14.4
28	112	13.45	13.2	12.4	13.5
100 Assumed	400	.....	3.69	4.24	4.57
1000 Assumed	4000	.....	0.369	.562	0.600
10000 Assumed	40000	.....	0.0369	0.070	0.0743

The rod was supported vertically in the center of the tank and measurements made with a Leeds and Northrup Wheatstone Bridge and an AC galvanometer. Careful and accurate measurements were made to determine the specific resistivity of the water. Salt was added to the tap water until the resistivity dropped to 990 ohm-cms. The results of the tests are shown in Table I along with corresponding values computed by Equations 3, 5 and 6.

Equation 3 is obviously not applicable to short rods but for lengths in excess of 64 diameters the agreement with the measured values is exceedingly good. It will be seen that both the Dwight and Peters formulae are in good agreement with the data throughout the practical range of vertical rod lengths. For the extra great depths assumed these equations give values considerably greater than Eq. 3. This is not surprising, as both formulae are based on an infinite expanse of the medium while Eq. 3 limits the resistance to the medium within the tank walls. As the dimensions of the rod on which measurements were made were small compared to the dimensions of the tank the Dwight and Peters formulae are fairly applicable to that range.

The curve shown in Figure 5 was obtained from the measured and computed values in Table I. Either of the very simple formulae, Eq. 3 and as modified by the factors in Figure 5, should give reasonably reliable values for the resistance of vertical ground rods. When using any of these equations to compute ground rod resistances the determination of ρ is necessary and the uncertain and variable character of this factor is usually much greater than the small error which may be introduced by the use of approximate formulae.

4. Resistance to Ground of Longitudinal Pipes

In practice it is often desirable to calculate the resistance to remote ground of a limited length of horizontal pipe which may be used as an anode. Dwight's Eq. 21, which is a covergent and endless expression and rather laborious to use, is applicable to such a body. However, as it applies only to the entire cylinder as a unit, including the fringing end effects, it is not suitable for determining the unit resistance of an indefinitely long cylinder, such as a cross country pipe line or even the resistance to radial flow of a section of pipe in a distribution network. Such data are often required in combination with potential gradient measurements in the earth in determining current densities at pipe surfaces, as will be explained later. Eq. 3, as developed for vertical ground rods, is equally applicable to horizontal pipes but in this case the disturbing condition is the proximity of the ground surface and not the end effect as with the vertical rod.

To study the effect of the ground surface on the resistance of horizontal conductors experiments were carried out in a slate tank 18.2 inches long, 18 inches wide and 20 inches deep. The bottom and the two inner sides of the tank were lined with thin sheet iron, the ends being left bare. A ¼-inch steel rod, 18.2 inches long to fit exactly the length of the tank was supported horizontally midway between the side

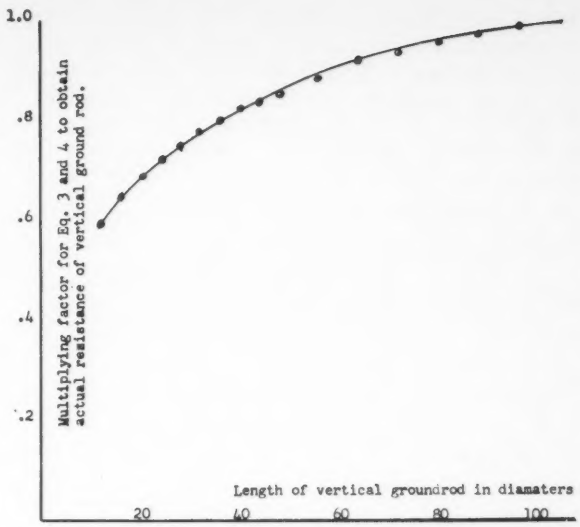


Figure 5—Multiplying factor for long ground rod formula.

walls, and measurements of resistances to the metal walls made at various depths, starting with the center of the rod ½-inch or 2 diameters below the surface of the water and continuing to a depth of 6 inches or 24 diameters. As the end walls were nonconducting there was no disturbing end effect. The depth effect is shown in Curve A, Figure 6. The resistivity of the water was determined accurately at 3732 ohm-cms. Taking D, the effective distance to remote ground, as 10 inches, the theoretical resistance of the rod to ground, assuming no border effect, was determined by Eq. 3, as follows:

$$R = \frac{0.012 \times 3732 \log_{10} \frac{10}{0.125}}{18.2/12}$$

$$= 29.4 \times \log_{80} = 29.4 \times 1.9 = 56.1$$

Based on the ratio between the calculated resistance, 56.1, and the measured resistances shown in Curve A, the insert curve in Figure 6 shows the factor Q, by which values determined by Eq. 3 must be multiplied to obtain correct unit resistances of horizontal pipes or rods to ground. It is of interest to note that the log factor in Eq. 3, as used for the small tank experiment, is 1.9 while that suggested for field use, where D is in the order of hundreds of feet, is 2.7.

Curves B to F, Figure 6, show corresponding resistances of two parallel rods to remote ground for different separations and depths. Curve G, the dotted curve, was obtained by substituting in Dwight's Eq. 21 as applied to the single cylinder. The fit with Curve A, with which it should coincide, is poor, particularly for the shallower depths. Nor does the Dwight formula seem to apply to very long pipe lines where the resistance to radial flow of current is required.

5. Multiple Ground Rods, Vertical and Horizontal

A number of tests were made in the 8-foot tank to determine resistances to ground of both vertical and horizontal electrodes in various geometric patterns and spacings. The electrodes were of cold rolled steel 15/64-inch in diameter. The length of the electrodes

was 2 11/32-inches or 10 diameters. These were intended to simulate graphite anodes of about seven feet in length which are often installed, surrounded with coke-breeze, to give an effective diameter of 1/10 to 1/7 of their length. The small diameter rod in combination with the 8-foot tank were intended to simulate or approximate field installations with respect to the ratio $\frac{D}{a}$. Resistance measurements were made between the electrodes and the walls of the tank by means of a Wheatstone bridge and an AC galvanometer. Some of the data so obtained are here given in Tables II to V. All depths and spacings are given in diameters of rod (d). The efficiency shown is that compared to a single unshielded electrode. For example, the efficiency of two rods at 10d spacing is the theoretical resistance, $\frac{100}{2}$ divided by actual resistance, 61.8, or 81 percent.

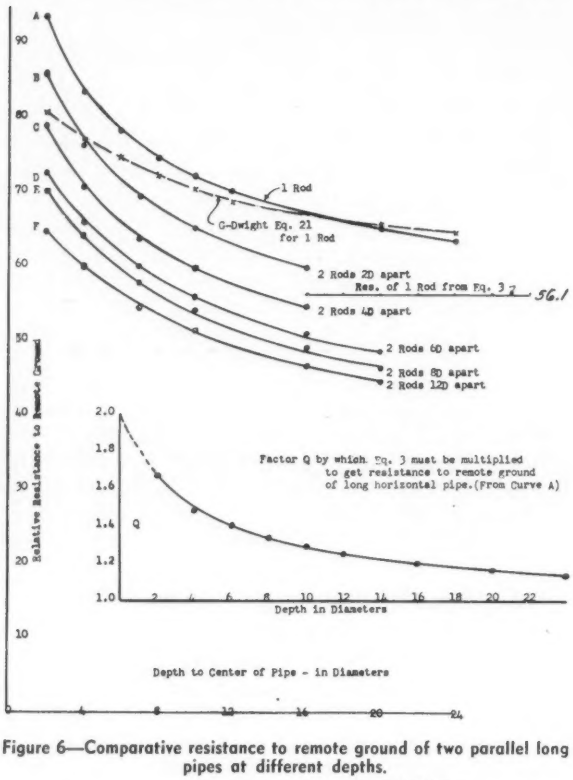

1 Rod
G-Dwight Eq. 21 for 1 Rod
2 Rods 2D apart
Res. of 1 Rod from Eq. 3
56.1
2 Rods 4D apart
2 Rods 6D apart
2 Rods 8D apart
2 Rods 12D apart
Relative Resistance to Remote Ground
Factor Q by which Eq. 3 must be multiplied to get resistance to remote ground of long horizontal pipe. (From Curve A)
Q
Depth in Diameters
Depth to Center of Pipe - in Diameters

Figure 6—Comparative resistance to remote ground of two parallel long pipes at different depths.

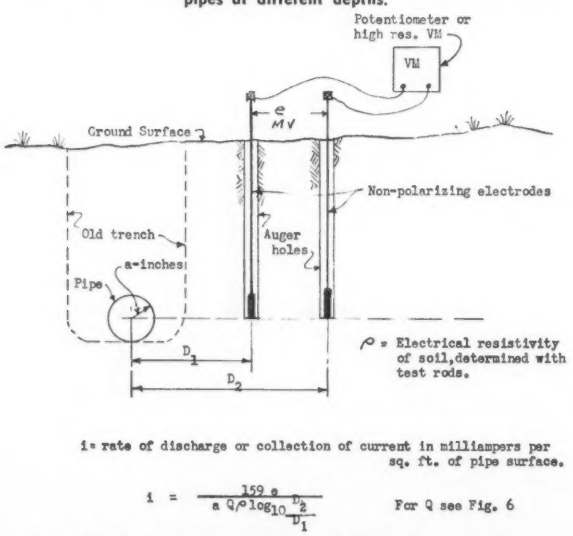

Potentiometer or high res. VM
VM
Ground Surface
Non-polarizing electrodes
Old trench
Auger holes
a-inches
Pipe
ρ = Electrical resistivity of soil, determined with test rods.
i = rate of discharge or collection of current in milliampers per sq. ft. of pipe surface.
$i = \frac{159\ e}{a\ Q \rho \log_{10} \frac{D_2}{D_1}}$
For Q see Fig. 6

Figure 7—Method of measuring current density at pipe surface.

6. *Determination of Current Density at Pipe Surface*

In Section 4 it was stated that Eq. 3 can be used in the determination of the density of the current flowing to or from a pipe line. Such a measurement may be required, either for evaluating the rate of

TABLE II

Resistance to Ground of Vertical Electrodes Submerged to Depths of 10d.

a. Spaced in line at 5d apart

No. of Electrodes	Comparative Resistance	Efficiency
1	100	100
2	70	71.5
3	54.5	61.1
4	46.2	54.1
5	40.4	49.5
6 Eff. $\frac{100}{6} / 36.1 = 46.2$	36.1	46.2
7	33.1	43.2
8	30.6	40.8
9	28.5	39.0
10	26.7	37.5
11	25.1	36.3
12	23.8	35.0

b. Same—spaced in line at 10d apart

1	100	100
2	61.8	81.0
3	46.0	72.5
4	37.9	66.0
5	32.5	61.5
6	28.6	58.2
7	25.7	55.6
8	23.3	53.5
9	21.4	52.0
10	19.8	50.5

c. Same—spaced 21d apart

1	100	100
2	56.9	88.0
3	41.0	81.3
4	32.7	76.5
5	26.3	76.1
6	23.6	70.5
7	20.9	68.3

d. Same—spaced 42d apart

1	100	100
2	53.5	93.5
3	33.6	89.2
4	26.1	86.3

e. Same—spaced 62d apart

1	100	100
2	52.3	95.5
3	36.1	92.4

f. Same on Equilateral Triangular Spacing

3 Spaced at 10d apart	48.6	68.5
3 Spaced at 15.7d apart	44.5	75.0
3 Spaced at 21d apart	42.7	78.0
4 Spaced on square with side of 10d	42.0	59.5

TABLE III

Resistance to Ground of Vertical Electrodes Submerged to Depth of 16d, and Spaced 21d apart.

No. of Electrodes	Comparative Resistance	Efficiency
1	100	100
2	58.9	85
3	43.5	76.5
4	35.0	71.5
5	29.6	67.7
6	25.7	65.0
7	22.8	62.5

stray current or galvanic action on a pipe or for determining the degree of cathodic protection it is receiving. In 1927 the National Bureau of Standards developed the McCollum[3] Earth Current Meter which was designed to accomplish this very thing. It has been used extensively for the study of stray current electrolysis on underground piping systems and to some extent in connection with cathodic protection investigations. This instrument embodies four fixed electrodes, equally spaced in line on a rigid insulating member. When this group of electrodes is placed in the soil, on a line radial from a pipe, either in the face of an excavation or in a vertical auger hole directly over the pipe, it is possible by electrical measurements to determine both the specific resistivity of the soil and the voltage gradient in the earth in the vicinity of the pipe. From these two measurements the current density in milliamperes per square foot at the pipe surface can be calculated.

Scott[4] has outlined a very simple method for calculating current densities on pipes, which includes potential gradient measurements at the ground surface and determination of the soil resistivity in the region where the potential gradient measurements are made. However, as the resistivity of the surface soil is often quite different from that at pipe depth and as such surface measurements must of necessity be made at a considerable distance from the pipe, the method cannot be considered as very accurate or reliable.

In Figure 7 is illustrated a method of determining current density which embodies the simplicity of the Scott method and the accuracy of the earth current meter. In the method here proposed two holes of about two inches in diameter are augered or driven to pipe depth at distances D_1 and D_2 from the center of the pipe. To avoid working in the old trench, it is preferable that both holes be in undisturbed soil, say at distances of about 24 and 42 inches. The resistivity of the soil at pipe depth can now be determined by the use of resistivity test rods or by any other approved method. In using the rods it is important that measurements be made with the rods first in one position and then reversed in the two holes. The average of the two readings should then be used in the calculations. The potential gradient in the soil between the two holes is also determined by the use of two non-polarizing electrodes and a potentiometer or high-resistance voltmeter. The standard electrodes and meter used for pipe-to-soil potential measurements can be used for this purpose.

Let I = current in ma; entering or discharging from 1 linear foot of pipe

i = current in ma per square foot of pipe surface

a = radius of pipe (outside) in inches

A = area in square feet of 1 linear foot of pipe $= \frac{2\pi a}{12}$

Then $I = Ai = \frac{2\pi ai}{12}$

or $i = \frac{6I}{\pi a}$

R_o = resistance to radial flow of current from D_1 to D_2 for 1 linear foot of pipe, from Eq. 3, $= 0.012\rho \log_{10} \frac{D_2}{D_1}$, where

ρ = resistivity of the soil in ohm-cms.

Let e = measured potential difference in millivolts between D_1 and D_2,

then $I = \frac{e}{R_o}$ (assuming uniform potential gradient and soil resistivity around pipe)

$$\text{or } i = \frac{6e}{\pi a R_o} = \frac{6e}{0.12\pi a\rho \log_{10} \frac{D_2}{D_1}} = \frac{159e}{a\rho \log_{10} \frac{D_2}{D_1}}$$

While this equation will probably give a fair approximation to the lateral current density, it will be somewhat greater than the average current density, because of the ground surface effect. To obtain the average current density it will be necessary to introduce the factor Q, as given in the insert curve, Figure 6. Our equation then becomes:

$$i = \frac{159e}{a\rho Q \log_{10} \frac{D_2}{D_1}} \qquad \text{(Eq. 7)}$$

To illustrate the magnitude of the quantities here involved, let us consider a 6-inch steel pipe buried to a depth of six diameters in a soil having a resistivity

TABLE IV

Resistance to Ground of Horizontal Electrodes with Axes All in the Same Line. Length of Electrodes = 10d. Depth of Axis = 4d.

a. Longitudinal Spacing = 20d or 10d between Ends

No. of Electrodes	Comparative Resistance	Efficiency
1	100	100
2	59	84.7
3	41.5	80.3
4	33.4	74.8
5	28.0	71.5
6	24.4	68.5
7	21.6	66.2
8	19.5	63.2
9	17.8	62.5
10	16.3	61.5

b. Longitudinal Spacing = 20d between Ends

1	100	100
2	52.5	95.2
3	37.1	89.7
4	29.1	85.8
5	20.8	80.0
6	.....	.....

TABLE V

Resistance to Ground of Horizontal Electrodes with Axes Parallel But Not in Line, Length of Electrodes = 10d, Depth to Center = 4d.

a. Spacing between parallel axes = 10d

No. of Electrodes	Comparative Resistance	Efficiency
1	100	100
2	62	81.6
3	48.1	69.2
4	39.6	63.2
5	34.9	57.2
6	30.0	55.5
7	27.1	52.7
8	24.6	50.6
9	22.8	48.7
10	21.1	47.5

b. Spacing between parallel axes = 20d

1	100	100
2	57.2	87.4
3	41.8	79.8
4	33.6	74.5
5	28.4	70.5
6	24.6	67.7

c. Spacing between parallel axes = 40d

1	100	100
2	53	94.5
3	38	87.7

of 1000 ohm-cms. Let us also assume that a potential gradient of 15 m.v. is observed between holes 24 and 42 inches from the center of the pipe. Substituting in Eq. 7, we have:

$$i = \frac{159 \times 15}{3.21 \times 1000 \times 1.4 \times \log_{10} 175} = \frac{0.531}{\log 1.75} = \frac{0.531}{0.243} = 2.18$$

7. Measurement of Soil Resistivity

In designing ground beds for either power station grounds or cathodic protective systems, the electrical resistivity of the soil is by far the most uncertain and variable factor. Not only does this property of the soil vary widely with geologic and climatic conditions, but in many locations it is non-homogeneous both vertically and areally. For this reason it is usually desirable, and in many instances quite necessary, to make a resistivity survey of the soil in any area where ground beds are contemplated.

Although test canes or rods are useful at shallow depths they are not well adapted to the depths at which large ground beds are usually installed. For this purpose it is customary to use the 4-electrode method, illustrated in Figure 8. In the application of this method a current of I amperes is passed from a battery, Ba, through an ammeter, Am, into the ground through ground rods C_1 and C_2 separated by a distance 3A, where A is termed the electrode interval. The potential drop, E, in volts, between two intermediate electrodes P_1 and P_2, placed as shown, is then read on the potentiometer, P. If the soil under test is homogeneous the specific resistivity in ohm-cms is given by the equation

$$\rho = \frac{191\ A\ E}{I} \qquad \text{(Eq. 8)}$$

where A is measured in feet. In practice, provision is made for periodically reversing the current and potential leads to eliminate galvanic and stray currents and polarization between the potential electrodes. If the resistivity of the soil varies with depth, the value of ρ obtained at any value of the electrode interval, A, will be an average value, the magnitude of which is determined largely by the soil within the depth A. While this is an imperical relation, it has been found by experiment to be sufficiently reliable for most practical purposes. By beginning with a small value of A, say two feet, and repeating the measurements with increasing values of A up to about 12 or 14 feet, and then plotting the calculated values of the apparent resistivity as ordinates against the corresponding values of A as abscissa, a graph is obtained which shows the manner in which the resistivity of the soil varies with depth. Typical resistivity curves are shown in Figure 9. The rising curve, M, shows that the surface soil is lower in resistivity than the deeper strata, while the falling curve, N, indicates a reverse relation. Such data are useful in determining suitable locations for power station ground beds and anode beds for cathodic protection systems. They are also helpful in designing such ground beds with respect to depth of burial and vertical or horizontal placement of electrodes. Where rising curves, similar to M, are obtained the anode units should be placed horizontal to avoid encountering high resistance soil, hard-pan gravel, or rock. Where a drooping cure is obtained, indicating decreasing resistivity with depth, it may be more economical to place the anodes in a vertical position to take advantage of the soil of low resistivity. Where the top soil is high in resistivity because of lack of moisture the condition may be corrected temporarily by application of water, and more effectively by the liberal use of salt.

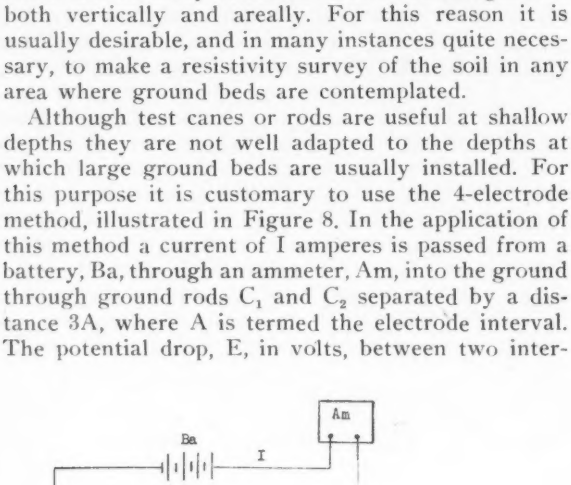


Figure 8—The 4-electrode method of measuring the electrical resistivity of soil.

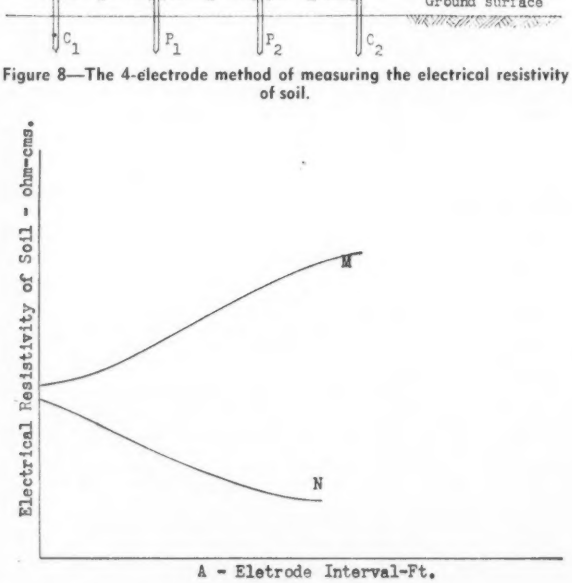


Figure 9—Typical electrical resistivity curves obtained by the 4-electrode method.

8. Design of Ground Beds for Cathodic Protection of Pipe Lines

Electric current used for cathodic protection of pipe lines is usually supplied from rectifiers energized from commercial power lines. Theoretically the most economical anode installation is one in which the annual cost of power is equal to the annual interest charge on the investment of the protective system. While practical considerations may at times modify this economic balance, it is obviously necessary to construct ground beds of low resistivity if excessive use of power is to be avoided. In practice a limiting rectifier voltage usually determines the resistance of the ground bed. Ten to 25 volts, DC, are customary, although higher values are occasionally used.

One type of ground bed in common use is old pipe in lengths of 50 to 200 feet buried parallel to and at a considerable distance from the line to be protected.

The greater the distance the more uniform will be the distribution of the cathodic current on the piping system. If possible, the anode should be at least 200 feet from the nearest pipe. If the soil resistivity is known the resistance to remote earth of such an anode can be predetermined with reasonable accuracy by Eq. 3 or 4, modified by the surface correction factor Q, Figure 6, and the end effect factor, Figure 5. As the correction factors of Figure 5 are based on the fringing effect at only one end and as the fringing takes place at both ends of a horizontal cylindrical anode, it will be necessary to use one-half the lengths shown in Figure 5 where horizontal anodes are concerned. As an example let us consider an 8-inch pipe 60 feet long in soil of 1000 ohm-cms resistivity buried to a depth of 5 diameters. By Eq. 4 we have,

$$R = \frac{0.0324 \times 1000}{60} = 0.54 \text{ ohm.}$$

The depth correction factor, Q, from Figure 6 is 1.45 and the end effect factor for 30 feet (42 diameters) as shown in Figure 5 is 0.83. The former effect increases the resistance while the latter decreases the calculated resistance. The true resistance is therefore, $R = 0.54 \times 1.45 \times 0.83 = 0.65$ ohm. By way of comparison, the resistance of this 60 feet of pipe to ground, by Dwight's Eq. 21, is 0.601 ohm.

The resistance of two parallel pipes as compared to that of a single pipe, for different depths of burial, is shown in curves A to F, Figure 6.

a. **Graphite Anodes.** Because of the wasting away of iron anodes and the present scarcity of scrap iron, graphite anodes are becoming increasingly popular. These are available in the form of 80-inch rods, four inches in diameter with a wire suitably attached to one end. These are usually installed in vertical holes 10 or 12 inches in diameter. The holes are then filled with finely powdered coke, termed coke breeze, to give the anode a larger effective diameter. When so installed the rod has a resistance, r, to remote earth, as determined by Eq. 4, and modified by Figure 5, of about $\frac{2.5\rho}{1000}$ ohms, where ρ is the resistivity of the soil. Where a number of such anodes, N, are installed in a straight line and connected in parallel, they will tend to shield one another and the combined resistance, R, to remote earth will be somewhat more than the theoretical resistance of $\frac{r}{N}$. We may, therefore, write $R = \frac{r}{KN}$, where K is the efficiency of the combined bed, as determined by the laboratory data recorded in Tables II to V.

If I is the current, in amperes, required for a cathodic installation, a balance between the rectifier voltage and the number of graphite anodes is determined as follows:

If E is the voltage of the rectifier to be used, E-1 can be assumed to be the effective voltage on the ground bed, allowing one volt drop in the metallic circuit. The desired ground bed resistance will then be,

$$R = \frac{E-1}{I}$$

The number of anodes, N, required to give a bed resistance of R will then be determined from the following relations:

$$R = \frac{r}{NK} = \frac{2.5\rho}{1000NK} = \frac{E-1}{I}, \text{ or}$$

$$N = \frac{2.5\rho\, I}{1000K\,(E-1)} \qquad \text{(Eq. 9}$$

Basic data which will be found useful in designing cathodic protection for piping systems will be found in tabular form in Appendix A. Also, in Appendix B are given the relative current densities on different sizes of interconnected pipes for a given potential difference between the piping system and remote ground.

B. Cathodic Protection of Large Water Tanks

1. *Factors Affecting Required Current Density and Design of Cathodic Protection and Installations*

a. Protective Coatings. In designing cathodic protective systems for large steel water tanks the most uncertain or variable factor is the condition of the interior paint coating. Most tanks have been painted at one time or have received at least a shop coat prior to erection. This coating, or what remains of it, in itself provides a certain degree of protection against corrosion. In new paint coatings, flaws, breaks, and weak or thin areas invariably develop and it is to provide protection against corrosion at these points that cathodic current is superimposed on the tank walls. Since high current densities will cause blistering of paint coatings, due to electric osmosis and high alkalinities at cathodic areas, it is likely that the tank coating will be gradually broken down, the rate of failure decreasing as more surface area is exposed. The prevention of damage to paint coatings will be discussed later in this paper after other design factors have been considered.

b. Relative Corrosiveness of Waters. The dissolved oxygen concentration in a water plays a most important role in its corrosiveness and, therefore, in the current density requirements. Work done by L. P. Sudrabin[5] indicates that "in quasi-stagnant corrosion media of water containing less than 1.0 ppm of dissolved solids, 0.1N and 1N NaCl solutions, with controlled oxygen concentration in the bulk of the media, the current density requirements for complete protection vary directly with the dissolved oxygen concentration." It must be remembered, however, that the presence of dissolved oxygen does not necessarily mean a water is corrosive. It merely means one of the more important factors in corrosion of metals by potable water is present. Other factors such as mineral content and concentration of other dissolved gases in the water being favorable, the dissolved oxygen will play a proportional role in the degree of aggressiveness. The importance of dissolved oxygen should not be underestimated, however, as it is generally true that a total absence of dissolved oxygen will render any dilute solution, within the total solids temperature range of potable waters, non-corrosive for all practical purposes.

These factors enumerated are only a few of the

many involved. In practice, when dealing with cathodic protection of water storage vessels it must be assumed that some dissolved oxygen will be present in the stored water, the amount depending upon water source, temperature, and degree of agitation and turn-over in the tank. For purposes of design, the mineral content of the water must be considered along with the dissolved oxygen concentration. For example, in waters containing high calcium and magnesium, deposits of these minerals tend to form on the cathodic area upon passage of current and thereby reduce current requirements. Many waters with high calcium and silica content and low sulfate and chloride content are not usually aggressive initially. However, where chlorides and sulfates are high, these waters may be very aggressive. The paradox presented here has a direct effect on the design of cathodic protection systems. The soft waters of low solid content are usually extremely corrosive and a high current density is required for protection. These waters are of high resistivity, however, and complicate anode designs necessary to apply the required current density at a reasonable voltage setting. The corrosive high solids waters, while requiring a higher current density than the median group, are of low resistivity and permit more liberal design at a reasonable voltage setting.

c. Selection of Current Density. As waters differ widely in their corrosiveness on their own merit, the magnitude of current densities that are necessary to protect iron and steel in different waters, under different conditions of surface protection is rendered even more complex. Polarization potential measurements, using a reference electrode, which is standard procedure for determination of the required current density for the protection of underground pipes against soil action, appear to be of little or no value when made on bright iron in the laboratory. The authors ran a number of such "Cathode Potential" vs. "Current Density" curves on natural waters of widely varying total solids content from different parts of the country. Figure 10 shows such a curve obtained by measuring the voltage between bright iron and a calomel electrode in water from Camp Kilmer, N. J. This water had total solids of 106 ppm and a resistivity of 6340 ohm-cms. The curve is typical of and almost identical with all of those obtained on potable waters from various parts of the country. It is evident from these tests that the standard polarization curve alone is of no particular value in identifying aggressive waters. On the basis of the usual interpretation for this curve it may be seen that a current density of approximately 5 m.a. per sq. ft. is required for protection, although 15 m.a. per sq. ft. is required to change the initial polarization voltage by 0.25 volt. There is considerable evidence to indicate that current densities in the order of the higher value here mentioned are necessary for the initial protection of bright iron in some waters. The important fact brought out by the laboratory tests here described is that initial polarization measurements in the laboratory, without considering other factors, are of little value in determining the degree of corrosiveness of a water.

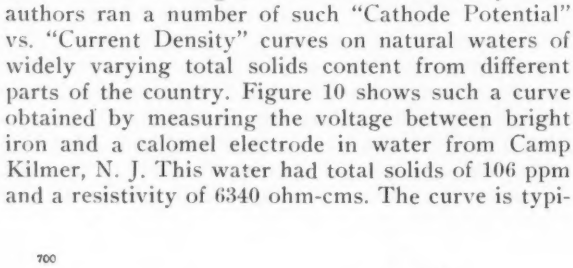


Figure 10—Polarization potentials between bright iron and a calomel electrode in water from Camp Kilmer, N. J.

Since so little is known about current density requirements under these manifold conditions, it would seem appropriate to assume that from 5 to 10 m.a. per square foot is necessary for protection of bare metal submerged in the majority of potable waters. On a painted tank we may liberally assume that only 10 percent of the surface area is exposed and, accordingly, an initial density of 0.5 to 1.0 m.a. per square foot should be ample for protection. On newly painted tanks, even this minimum figure may be high. Likewise, for a new unpainted tank on which the shop coat will afford partial protection, and also on old tanks which have not been painted for some time an intermediate current density of 2.5 to 5.0 m.a. pe square foot is suggested.

Whatever density is selected, it is considered ad visable to select test areas on the tank surface where the degree of protection can be observed frequently during the first year of operation and occasionally thereafter. The use of bright steel coupons and/or polarization potential measurements will be helpful when employed in conjunction with observation of the tank surface. However, such criteria are not always reliable indices of protection.

To procure the wide latitude in current densities here indicated, rectifiers of ample capacity and voltage range should be provided. Redesign and replacement of the anode system may be required from time to time in accordance with changing conditions of the tank coating. Rectifiers capable of supplying any voltage from 1 to a maximum of 12 to 15 volts are usually appropriate.

d. Possible Injury to Paint Coating. A factor which should not be neglected is the possibility of injuring the paint coating by application of excessive voltage. To avoid this the operating voltage should not be greatly in excess of that required to overcome the resistance between the anode and the bare walls. Any voltage greater than this will be concentrated across the paint film and, if in excess of a few tenths of a volt, will tend to cause blistering, loosening, or otherwise injure the coating. For this reason it is suggested that the voltage drop through the coating be limited to a maximum of 1 volt. The resistance of the paint coating can be determined approximately

by subtracting the calculated resistance of the tank circuit on the basis of bare metal, as hereafter described, from the actual resistance, as determined from ammeter and voltmeter readings of the rectifier. It is then a simple matter as shown in Appendix C to calculate the current that will flow under a pressure of 1 volt through the paint coating, whose resistance is now known. The rectifier output should then be limited to that total current.

e. **Resistivity of Water.** Another highly variable factor affecting the design of a cathodic installation for tanks is the electrical conductivity of the water. This property which is the reciprocal of the electrical resistivity approximates, for most potable waters, a straight line relation to the total solids present and varies in potable waters from about 30 micromhos for 1 cm in very pure water to approximately 2000 micromhos in highly mineralized water. Accordingly, the specific conductance of a water in micromhos can be obtained close enough for design purposes by multiplying the total solids present in the water in ppm by the factor 1.6.

As it is customary to base calculations and designs on electrical resistivity values (ohm-cms) rather than conductivity, a conversion of one unit to another is often desirable. This is accomplished as follows:

Let C = Conductivity in micromhos.
ρ = resistivity in ohm-cms.
T = total solids in ppm.
Then C = 1.6 T

$$\text{Also } \rho = \frac{1{,}000{,}000}{C} = \frac{625{,}000}{T} \qquad \text{(Eq. 10}$$

2. Design of Cathodic Protection System

a. **Anode Materials.** For the protection of hot water tanks, and other metal structures of relatively small area, galvanic anodes of zinc or magnesium are frequently used, as they require no external sources of power and no maintenance during their normal life. As the potentials delivered by these metals are not always sufficient for adequate protection of the large storage tanks with which we are concerned in this discussion it is customary to use rectifiers from which any desired voltage can be obtained. Such rectifiers are essentially the same as or identical with those used for the protection of underground piping systems, although usually of smaller capacity. Various kinds of anodes are in use on rectifier installations, chief of which are aluminum and platinum. The former are available and suitable in alloy or pure aluminum in rods of 5/8-inch to 1¼-inch diameter. The material has a theoretical life of 6.5 pounds per ampere year, corrodes in a fairly regular and uniform manner and the products of corrosion are harmless and do not discolor the water. The aluminum alloy rods have shown improved qualities of uniformity of attack over the pure aluminum rod. Platinum electrodes are practically immune to the action of the current and therefore are indestructible and permanent. They must be of very small diameter because of the high cost of the material. In cold climates they are also subject to breakage by ice if not removed during the winter months. The same may be said for aluminum and all other types of electrodes. For this reason it is customary to remove anodes from the water during the ice forming periods or design the total metal weight on a 1 year basis, expecting to replace the anodes each spring. Removal during the winter is not objectionable, as little corrosion of iron takes place at low temperatures.

b. **Anode Configurations.** To obtain a uniform distribution of current on the bottom and walls of a tank a careful balance between the number, length, and arrangement of the anodes is important. In this connection the discussion on Vertical Ground Rods under Section 3 and the curves in Figures 4 and 5 should be kept clearly in mind. For a vertical 1-inch rod, 6 feet (72 diameters) or more in length the end effect will be about 5 percent, as shown in Figure 5. The resistance between such a rod suspended vertically at the center of the tank and the tank walls can therefore be calculated with a high degree of accuracy by Eq. 3, if the resistivity of the water is known. Furthermore, laboratory tests on a small scale show that the resistance of such a rod varies only slightly with displacement from the center and also that several rods in parallel, well separated from each other, have a high efficiency and will deliver current to the tank walls and bottom almost in proportion to the number of rods or total length so connected. In water of very low resistivity a single rod at the tank center may suffice to give the required current, exclusive of the riser. Where only one rod is used its length should be such that the distance from the rod to the tank walls is approximately the same as that to the bottom, as shown in Figure 11 (a). For water of higher resistivity, three, four, or more rods symmetrically arranged as shown in Figure 11 (a), at distance R_a from the center may be required. Here they will be somewhat longer than a single center rod to again

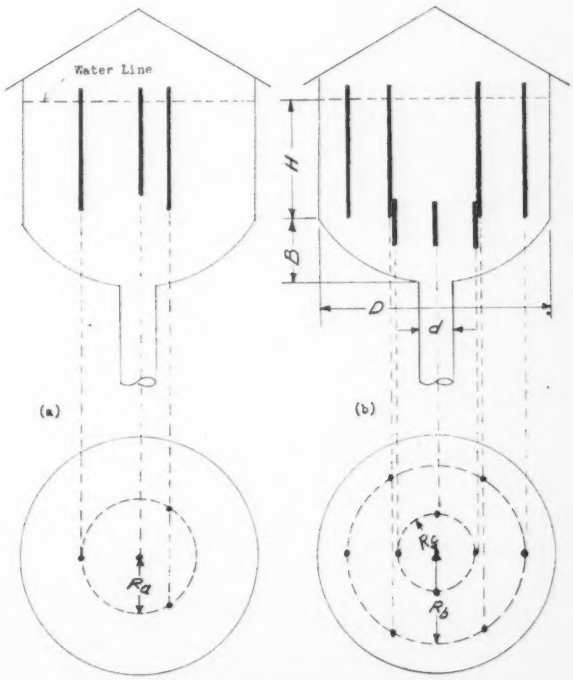


Figure 11—Arrangement of anodes in steel water tanks.

keep the distances to walls and bottom about equal. For water of very high resistivity the number of rods can be increased to form some such pattern as shown in Figure 11 (b). Here six long rods are shown symmetrically placed at a distance R_b from the center, to give protection to the walls and a portion of the bottom. Four additional short rods are shown, their function being to protect the center portion of the tank bottom. Such an arrangement of anodes when properly adjusted for length and radial position will give a fairly uniform distribution of current on the entire tank surface. A still larger number of anodes may be used as required. In any arrangement the radial distance R_b should be so selected as to make the distance from the anodes to the wall roughly one-half the distance between adjacent anodes. The same may be said for the anodes protecting the bottom of the tank. The efficiencies of some of these anode arrangements as compared to a single central electrode are shown from the following laboratory experiments.

An oil drum 22 inches in diameter was filled with water to a depth of 24 inches. A ⅛-inch steel rod was submerged to a depth of 20¾ inches at the center of the tank and was found to have a resistance to the tank of 38.4 ohms. At 5 inches from the center the resistance was 36.9 ohms and when moved to within ½-inch of the tank wall the resistance was 27.9 ohms. With a 5/16-inch rod the corresponding figures were as follows:

At center	R = 30.4 ohm	
At 5″ from center	R = 28.9	
At ½″ from wall	R = 16.3	
		Eff. %
For one 9/32″ rod at center	R = 31	100
For one 9/32″ rod 5½″ from center	R = 30	103
For three 9/32″ rods in parallel symmetrically placed 5½″ from center $\frac{31}{3}$ /11.3	R = 11.3	91.5
For three 9/32″ rods in parallel symmetrically placed 2¾″ from center	R = 14.3	72.5

The results of these tests indicate that the resistance of a vertical anode decreases as it is displaced from the center of the tank or that it will deliver more current in an eccentric position than at the center. It is of course, obvious that the distribution of current on the tank wall becomes more and more unsymmetrical as the rod is displaced from the center.

A false bottom of sheet iron was placed in the oil drum at a depth of 8½ inches below the water surface to form a small tank approximating the shape shown in Figure 11. The dimensions, referring to Figure 11, were as follows: D = 22 inches, H = 8½ inches, B = 2½ inches. Electrodes of 1/16-inch steel drill rod were used in the following tests. If all dimensions are multiplied by 16 the experimental tank will correspond to one of approximately 64,000 gallons capacity, having a diameter of 29.4 feet and a height of 11.3 feet and with electrodes of 1-inch diameter.

Six electrodes were symmetrically placed at a distance of 5½ inches from the center, or on a radius of ½ that of the tank, and at a depth of 7½ inches. Their combined resistance in parallel was 19.4 percent of the resistance of a single electrode at the center. Comparing the resistance of one inch of a rod under the two conditions, the efficiency of the group is:

$$\% \text{ Efficiency} = \frac{N_1 (100)}{N_2 \times \frac{R_2}{R_1}}$$

Where R_1 is the measured resistance of the single center. Comparing the resistance of one inch of a system, and N_1 and N_2 the respective total anode lengths in inches.
Therefore,

$$\text{Efficiency of Group} = \frac{7.5 (100)}{45 \times .194} = 86\%$$

The six 1/16-inch electrodes were then arranged symmetrically at a distance of 7½ inches from the center, or on a radius ¾ that of the tank, and submerged to a depth of 7 inches (3½ inches from the bottom). The combined resistance in parallel of the six electrodes in this position was 17.25 percent of the resistance of a single 1/16-inch rod at the center. The efficiency of such a group is, therefore $\frac{7 (100)}{42 \times .1725}$ or 96.7 percent. With 12 1/16-inch electrodes on the same radius and to the same depth of 7 inches, the combined resistance in parallel was 10.55 percent of the resistance of a single electrode at the center. The efficiency of this group therefore, is

$$\frac{7 (100)}{84 \times .1055} = 79\%.$$

A group of 10 1/16-inch rods was arranged as in Figure 11 (b). These included the 6 rods at distance 7½ inches from center and 7 inches deep as above, and four short rods, 2½ inches long, on a 3½-inch radius, with the bottom ends 3 inches from the bottom of the tank bowl. The combined resistance in parallel of all 10 rods totalling 52 inches in length was 16.9 or 15.35 percent of the resistance of a single center rod. The efficiency of this group, therefore, is

$$\frac{7 (100)}{52 \times .1535} = 87.5\%.$$

It is of interest to compare the calculated resistance of the 10 rods with the actual resistance of 16.9 ohms, as determined by the Wheatstone Bridge and AC galvanometer. To do this the resistivity of the water must be known. This was determined to be 2140 ohm-cms in a conductivity cell. The calculated resistance of one 7-inch rod at the center is (by Eq. 3)

$$R = \frac{.012 \times 2140 \log 22/\frac{1}{16}}{7/12} = 44 \times 2.546 = 112 \text{ ohms.}$$

Since this rod has a length in excess of 100 diameters there is no depth correction, as shown in Figure 5. The resistance of six such rods allowing no change for displacement from center and none for mutual shielding (as one effect tends to counteract the other) is 112/6 = 18.67 ohm. As the separate resistances, to ground, of two rods are inversely proportional to their lengths, the resistance of a 2¼-inch rod should be $r = \frac{7}{2\frac{1}{4}} \times 112$, or 348 ohm. As the fringing end effect takes place at both ends of the short rods, the depth correction must be applied to

½ the length, as previously explained, which in this instance is 1⅛ inch or 18 diameters. Referring to Figure 5 we find the correction for a length of 18D to be 0.67. The actual resistance of the short rod, is, therefore, 0.67×348 or 233 ohms, and of four such rods 233/4 or 58.4 ohms. The combined resistance of all 10 rods in parallel can now be obtained by taking the reciprocal of the sum of the two reciprocals, thus, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$. Substituting the calculated values above, we have

$$R = \frac{1}{\frac{1}{18.7} + \frac{1}{58.4}} = \frac{1}{.0535 + .0171} = \frac{1}{0.0706} \quad \text{or } R = 14.16 \text{ ohm,}$$

as compared with the actual measurement of 16.9 ohm, giving an efficiency for the 10 rod installation of 83.8 percent, as referred to a single center rod.

The correlations between the actual and computed resistances of the single rods is remarkably close. For the long rod at the tank center the value calculated by Eq. 3 is 112 ohms as compared with the measured value of 110 ohms. For the short submerged rod the computed value is 233 ohms as compared with the measured value of 239 ohms when displaced 3½ inches from the center. The computed resistance of the 10 rods is somewhat less than the actual resistance because of mutual shielding, but this effect is less than might be expected without the experimental data here reported. The efficiencies of 86, 96.7, 87, 79, and 87.5, for the several arrangements of anodes described are so high that it would appear appropriate to base designs solely upon the total length of anode material if proper consideration is given to uniform distribution of the current. The following proposed designs illustrate the method of applying the principles and experimental data here discussed.

Examples of Cathodic Protection Design

Cathodic protection is required for a 50,000 gallon steel tank similar to that shown in Figure 11, having dimensions as follows:

	Feet
D, The diameter of the tank	= 26
H, The submerged height of the barrel	= 9
B, The height of the bowl	= 6½
d, The diameter of the riser	= 4
h, The height of the riser	= 50

As the tank is painted, a current density of 1 m.a. per sq. ft. is assumed to be adequate. Designs will be suggested for waters of three different resistivities, as follows:

a) = 900 ohm-cms.
b) = 3000 ohm-cms.
c) = 9500 ohm-cms.

The area of the drum is $\pi \times 26 \times 9 = 735$ sq. ft.
The area of the bowl is estimated at 757 sq. ft.
Total area of walls and bowl = 1492 sq. ft.

The area of the riser is $\pi \times 4 \times 50$, or 628 sq. ft. At 1 m.a. per sq. ft. the current requirement for the barrel and bowl is 1492 m.a. = 1.492 amperes, and that for the riser is 0.628 ampere.

Design (a) for $\rho = 900$ ohms-cms. Assuming that 1-inch aluminum rod will be used in the center of the barrel, the resistance of 1 foot of such rod from rod to tank will be, by Eq. 3,

$$R = 0.012 \times 900 \times \log \frac{26 \times 12}{1}$$
$$= 10.8 \log 312 = 10.8 \times 2.496 = 27.0 \text{ ohm}$$

(The log values can be taken directly from Figure 4 with sufficient accuracy)

The next step in determining the number of feet of anode required is preferably a trial and error or a "cut and try" process. Several factors must be considered, including the rate of deterioration of the anode and the limiting of the rectifier voltage to practical values. The chief consideration, however, is a proper placement and distribution of electrodes by which a reasonably uniform distribution of current in the tank surface is attained.

As the tank in question has a rather large ratio of diameter to height it is not possible to adequately protect both walls and bottom with a single central electrode. It is proposed, therefore, that six electrodes each 6 feet in length be installed symmetrically on a 7-foot radius. These will be six feet from the tank wall and from 5 to 7 feet from the bottom of the bowl. The resistance of the 36 feet of anode will be approximately 27.0/36 or 0.75 ohm. The voltage required to deliver the 1.492 amperes will be $E = 1.492 \times 0.75$, or 1.12 volts. It is obvious that to limit the current to 1.0 m.a. per sq. ft., or thereabout, a very low voltage will be required. With water of very low resistivity as here considered, it may be desirable to add some artificial resistance in the rectifier circuit. It has been assumed that no resistance is encountered by the current at the tank surface, but on freshly painted or coated tanks the resistance may be higher than the calculations indicate. Where this condition is found the actual current densities at points where the current reaches the tank surface will be higher than that assumed in the design, and the operating voltage should be limited to avoid damage to the paint coating as previously explained.

Protection of the riser requires an independent calculation, as it is not feasible to combine the resistance of the riser anode with that of the bowl anodes. It is customary to extend a separate, and usually a smaller anode rod the full length of the riser. The current density on the riser is usually higher than on the tank proper but this is not particularly objectionable as it usually constitutes a small portion of the the total area concerned. In the tank under consideration a ⅝-inch aluminum anode 48 feet long will be considered. The resistance per foot will be $0.012 \times 900 \times \log \frac{48}{5/8}$, or 21 ohms. The resistance of 48 ft. will be $\frac{21}{48}$, or .438 ohm. With the same voltage 1.12 as that required for the tank the total current will be 1.12/.438 or 2.56 ampere or 4.1 m.a. per sq. ft. Here it may be desirable to introduce resistance in the riser anode circuit to limit the current to not more than one ampere, the calculated requirement being 0.628 ampere.

A further check on the design should now be made to determine the life of the proposed anode system.

Aluminum alloy anodes similar to Alcoa, Type 17S-T have been found generally satisfactory because of the uniform rate of metal loss. The weight loss of this type of aluminum has been found by test to be 7.4 pounds per ampere year. In the design under consideration the current per foot of 1-inch anode is $\frac{1.492}{36}$ or .0415 amp. The annual loss per foot of anode will therefore be $7.4 \times .0415$ or 0.307 pound. As 1 foot of 1-inch aluminum weighs 0.914 pound the life for a 2/3 loss of weight will be $\frac{2/3 \times 0.914}{.307}$ or almost exactly two years. In a similar manner the life of the ⅝-inch rod in the riser, weighing 0.375 pound per foot, and discharging $\frac{2.56}{48}$ or 0.0523 amp. per foot will have a life of $\frac{2/3 \times 0.357}{7.4 \times 0.0523}$ or 0.62 year. If a one year life expectancy is to be attained for this riser anode, a current limiting resistance must be installed in the circuit, as previously suggested, or a larger rod used.

Design b) for $\rho = 3000$ ohms-cms. The only difference between this design and the one for $\rho = 900$ is in the voltage requirement. This will be higher in proportion to the resistivities, or $1.12 \times \frac{3000}{900} = 3.73$ volts.

Design c) for $\rho = 9500$. If the same anode arrangement is used here as in the other designs the required voltage will be $1.12 \times \frac{9500}{900}$, or 11.8 volts.

Here is will be definitely desirable to limit the current on the riser anode as otherwise the voltage gradient through the paint coating will be excessive and may injure the bond between the paint and the metal.

A modification of the anode arrangement proposed for Design c) which will give a better distribution of current on the bottom of the bowl and also permit a lower voltage in the high resistivity water would include six 1-inch rods 7 feet long, symmetrically placed on a 9-foot radius and four 1-inch anodes 3 feet long on a 4½-foot radius. The long rods would be 4 feet from the tank wall and would reach to within 3½ feet from the curved bottom of the bowl. The 3-foot rods would be suspended by insulated wires to reach within 3½ feet from the curved bottom of the bowl. The standpipe anode should extend about 2½ feet above the bottom line of the bowl. The total length of rod, exclusive of the standpipe anode, will be $6 \times 7 + 3 \times 4$, or 54 feet. The resistance of one foot of rod in the 9500 ohms-cms water will be $27 \times \frac{9500}{900}$, or 285 ohms, and for 54 feet will be 285/54 or 5.28 ohms. To deliver 1.492 amperes the operating voltage will be 5.28×1.492 amperes, or 7.9 volts. To allow for deterioration of the paint coating and other variable and uncertain factors mentioned previously which may eventually require a greater current, a 10 ampere rectifier with voltage range of 1.5 to 24.0 volts would be appropriate.

It will be noted that this design is based on 100 percent efficiency of the total length of anode. If fringing effect is included, the resistance of 1 foot of 1-inch anode in a 9500 ohm water, as calculated above, is 285 ohms. Six rods 7 feet long, or 42 feet of rod, will have a resistance of 285/42 or 6.785 ohms. Likewise, since 1 foot of rod has a resistance of 285 ohms, a 3-foot rod will have a resistance of 285/3 or 95 ohms, less the correction for fringing effect. As mentioned previously ½ the length of the short rods

APPENDIX A

BASIC DATA

R = Electrical resistance to radial flow of current to or from remote ground (100′ distant) of 1 lineal foot of pipe, neglecting surface border effect = $\frac{0.012\rho \log_{10} \frac{100'}{\frac{a''}{12}}}{}$

ρ = Specific resistivity of soil, ohms cms

a = Outside radius of pipe, inches

d = Outside diameter of pipe, inches

A = Area of lineal foot of pipe—square feet = 0.262d

W = Weight 1 lineal foot of pipe, pounds

C = Conductance of 1 foot of pipe to ground = $\frac{1}{R}$

R_o = Electrical resistance in ohms of 1 lineal foot of pipe = $\frac{215.8 \times 10^{-6}}{W}$

SIZE	d	a	A	W	R	C	R_o
¾″ Std.	1.05	.525	.275	1.13	.04ρ	25.0/ρ	191.0×10^{-6}
1	1.315	.658	.344	1.68	.039ρ	26.0/ρ	128.0×10^{-6}
1½	1.9	.95	.497	2.72	.037ρ	27 0/ρ	79.0×10^{-6}
2	2.375	1.187	.622	3.65	.036ρ	28 0/ρ	59.0×10^{-6}
3	3.5	1.75	.917	7.58	.034ρ	29.0/ρ	28.4×10^{-6}
4	4.5	2.25	1.18	10.79	.0328ρ	30.5/ρ	20.0×10^{-6}
6	6.625	3.21	1.736	18.97	.031ρ	32.0/ρ	11.4×10^{-6}
8	8.625	4.31	2.26	24.7	.029ρ	34.5/ρ	8.7×10^{-6}
10	10.75	5.38	2.82	34.3	.028ρ	36/ρ	6.3×10^{-6}
12	12.75	6.38	3.34	43.8	.027ρ	37/ρ	4.9×10^{-6}
14	14	7	3.66	45.7	.027ρ	37/ρ	4.7×10^{-6}
16	16	8	4.19	52.3	.026ρ	38/ρ	4.13×10^{-6}
18	18	9	4.71	59.0	.025ρ	40/ρ	3.66×10^{-6}
20	20	10	5.24	78.6	.025ρ	40/ρ	2.74×10^{-6}
6 Spiral	6.0	3.0	1.57	8.64	.031ρ	32.0/ρ	25.0×10^{-6}
8″	8.0	4.0	2.1	11.58	.030ρ	33.3/ρ	18.7×10^{-6}
10″	10.0	5.0	2.62	14.33	.0285ρ	35.2/ρ	14.8×10^{-6}

APPENDIX B

Relative Current Densities on Different Sizes of Interconnected Pipes for a Given Potential Difference to Remote Ground. (Remote Ground taken at 100 ft.)

Let i_{10} = Current density in ma/sq. ft. on 10″ Standard pipe

i_x = Current density in ma/sq. ft. on pipe of diameter X

I_{10} = Current flowing to or from 1 lineal foot of 10″ pipe

I_x = Current flowing to or from 1 lineal foot of pipe of diameter X.

A_{10} = Area in sq. ft. of lineal foot of 10″ pipe

A_x = Area in sq. ft. of 1 lineal foot of pipe of diameter X

R_{10} = Resistance to radial flow of current for 1 lineal foot of 10″ pipe (See App. A).

R_x = Resistance to radial flow of current for 1 lineal foot of pipe of diameter X

Then $I_{10} = i_{10} A_{10}$ and $I_x = i_x A_x$

Also $\frac{I_{10}}{I_x} = \frac{R_x}{R_{10}} = \frac{i_{10} A_{10}}{i_x A_x}$ Also $\frac{I_{10}}{I_x} = \frac{R_x}{R_{10}} = \frac{i_{10} A_{10}}{i_x A_x}$ or

$$i_x = \frac{i_{10} A_{10} R_{10}}{A_x R_x} = \frac{2.82 \times 0.028 \rho}{A_x R_x} = \frac{0.079 \rho}{A_x R_x} \quad \text{Eq. 2}$$

Substituting values of A_x and R_x from App. A, we have the following:

RATIOS OF CURRENT DENSITIES

¾″ Std. Pipe	$i = 7.2\ i_{10}$	20″ Std. Pipe	$0.60\ i_{10}$
1	$5.9\ i_{10}$	6″ Spiral	$1.62\ i_{10}$
1½	$4.3\ i_{10}$	8″ Spiral	$1.26\ i_{10}$
2	$3.5\ i_{10}$		
3	$2.5\ i_{10}$	10″ Spiral	$1.06\ i_{10}$
4	$2\ 04\ i_{10}$		
6	$1.47\ i_{10}$		
8	$1.2\ i_{10}$		
10	$1.0\ i_{10}$		
12	$0.87\ i_{10}$		
14	$0.80\ i_{10}$		
16	$0.725\ i_{10}$		
18	$0.67\ i_{10}$		

will be taken, to allow for fringing on both ends, thus 18 inches of 1-inch rod (18D) has a correction factor from Figure 5 of 0.67. The corrected resistance is therefore 95×0.67 or 63.65 ohms for one rod and 63.65/4 or 15.91 ohms for the four short rods. The total resistance of all anodes in parallel will therefore be

$$\frac{1}{\frac{1}{15.91}+\frac{1}{6.785}} = \frac{1}{.0629}+\frac{1}{0.1474} = \frac{1}{.2103} = 4.76 \text{ ohms.}$$

As can be seen, neglecting the fringing effect results in an error of approximately 10 percent, but as the error in this assumption, according to laboratory tests, is considerably less than the marginal allowances in the selection of the rectifier voltage and current capacities, a more precise method of design does not appear to be necessary.

c. **Platinum Electrodes.** The design for platinum electrodes will differ from that just outlined, chiefly in the resistance between the anode and the tank wall, and therefore in the voltage requirement of the rectifier. For an anode of 1/32-inch diameter in a 26-foot tank, and water of resistivity 900 ohms-cms, we have for the resistance of one foot of anode, by Eq. 3, $R = .012 \times 900 \times \log_{10}(26 \times 12 \times 32) = 10.8 \log 9984 = 10.8 \times 3.905 = 42.1$ ohms, as compared with 27.0 ohms for the 1-inch aluminum rod. For the same current and the same anode arrangement proposed for the aluminum anodes, the required voltage for the platinum anodes will be $E = \frac{42.1}{27} \times 1.12$, or 1.75 volts. As the platinum electrodes are not acted upon by the current, a slightly higher voltage may be needed to allow for chemical reactions. The economic aspects in the use of platinum electrodes are discussed in Appendix C.

Another difference in the designs of the two types of electrodes is in the linear resistance of the fine platinum wire. Because of this, it is customary to extend a feeder conductor along the anode, and supply current to it at several points, particularly on long anodes as those in the riser portion of the tank.

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APPENDIX C

Condensed Guide for Design of Cathodic Protective Systems for Steel Water Storage Tanks

In the design of cathodic protective systems for water storage tanks and also in checking specifications for same, a number of factors and variables must be considered, chief among which are the following:

A, the wetted area of the tank walls and bottom in square feet;
i, the required current density in ma per square feet;
ρ, the electrical resistivity of the water in ohm-cms;
R, The electrical resistance between the anode system and the tank in ohms;
E, the voltage between the anodes and tank wall. This will be slightly less than the rectifier voltage because of line drop;
I, the total current in the circuit in amperes;
L, the total length of the anode system in feet (assuming aluminum rods or platinum wire);
y, the years of service required of aluminum anodes with a 70 percent loss of weight;

Using the above nomenclature we can start with the fundamental equation of Ohm's Law,

$$E = IR, \text{ and since } I = \frac{iA}{1000}$$

$$E = \frac{iAR}{1000}$$

For 1-inch aluminum or aluminum alloy anodes

$R = \frac{0.12\rho \times 2.5}{L}$ (Eq. 3) approximately, since, as has been shown, the amount of current delivered to the tank walls and bottom with a given voltage is almost directly proportional to the total length of the anode system, and also the log factor in Eq. 3 is approximately 2.5 for 1-inch anodes in large tanks. Therefore

$$E = \frac{0.03\,iA\rho}{1000} \text{ or}$$

$$EL = \frac{0.03\,iA\rho}{1000} \qquad \text{(Eq. A}$$

Using this formula, it is possible to balance E and L at will, so long as their product equals the product of the known quantities on the right hand side of the equation. However, in actual practice, another factor, y, the life of the anodes, must be considered.

Aluminum rod of 1-inch diameter weighs 0.914 pound per foot and has a weight loss of 6.5 pounds per amp. year.* For a life of one year, assuming a 70 percent loss of weight, the corresponding current will be $\frac{0.7 \times 0.914}{6.5}$ or 0.0985 amp. per foot. Therefore, the current which L feet of rod will deliver for y years will be $I = \frac{0.0985L}{y}$ or $L = \frac{Iy}{0.0985}$. (Eq. B

In the practical application of these formulae, any desired value of E may be selected, so long as the corresponding value of L is satisfied by Eq. B. As an example let us consider the following conditions:

A hemi-ellipsoidal tank of 300,000 gallon capacity has a wetted area of walls and bowl of 5000 square feet. It is desired to provide for an ultimate or maximum current density of 5 ma per square foot. Solutions are required for

$\rho = 900$, for which $y = 1$
$\rho = 3000$, for which $y = 3$, and
$\rho = 9000$, for which $y = 5$

The line drop between rectifier and anodes is neg-

* A more practical unit developed by test for Alcoa 17S-T Aluminum anodes is 7.4 pounds per ampere year.

lected in the following calculations concerned with aluminum anodes:

Solution 1, $\rho = 900$, $y = 1$

$$I = \frac{Ai}{1000} = \frac{5000 \times 5}{1000} = 25 \text{ amperes}$$

From Eq. B, $L = \frac{I\,y}{0.0985} = \frac{25}{0.0985} = 254$ ft.

This is the minimum length of rod that can be used to give a life of one year.

From Eq. A, $EL = 0.03 \times 25 \times 900 = 675$

The maximum value of E that can be used is $E = \frac{675}{254}$ or 2.66 volts.

A practical solution would call for some ten symetrically placed anode rods about 20 feet in length, and four stub electrodes, each four feet long.

Solution 2, $\rho = 3000$, $y = 2$

I = same as in solution 1 = 25 amperes

From Eq. B, $L = \frac{25 \times 2}{0.0985} = 508$ ft.

From Eq. A, $EL = 0.03 \times 25\ 3000 = 2250$ or E max. $= \frac{2250}{508} = 4.43$ volts.

A practical solution would call for some 24 anodes 20 feet long and six stub anodes 5 feet long.

Solution 3, $\rho = 9000$, $y = 3$, $I = 25$

From Eq. B, $L = \frac{25 \times 3}{0.0985} = 760$ ft.

From Eq. A, $El = 0.03 \times 25\ 9000 = 6750$ or E max. $= \frac{6750}{760} = 8.9$ volts.

Because of the great length of rod required in this example, a three-year life of anodes for the protection of bare tanks does not appear to be practicable.

The above solutions are based on an ultimate maximum current density of 5 ma per sq. ft. which may be required only after many years of service during which time the paint coating gradually deteriorates. It is considered appropriate, however, to provide in the original installation sufficient rectifier capacity and voltage control to give adequate protection under all conditions of the coating. For this reason rectifiers should be so constructed as to give any desired voltage in units from one to the maximum. Also it is apparent that smaller than 1-inch anodes may suffice during periods of low current requirements.

Avoidance of Paint Damage

Under no circumstances should the rectified voltage be high enough to injure the paint coating on the interior of the tank. To avoid this the operating voltage should not be greatly in excess of that required to overcome the resistance between the anode and bare tank walls. Any voltage in excess of this will be concentrated across the paint film and should not be greater than approximately one volt. To illustrate this point let us consider an example where

$R = \frac{0.012\rho \times 2.5}{L}$, $L = 50$ ft. and $\rho = 3000$, therefore

$$R = \frac{0.012 \times 3000 \times 2.5}{50} = 1.8 \text{ ohms}$$

This is the calculated resistance between the 50 feet of anode and the bare tank walls. For this analysis it is necessary to include the resistance of the line wires between the rectifier and the anodes and tank wall. In our example let us assume the line to consist of 140 feet of No. 10 copper wire having a resistance of 1.02 ohms per 1000 feet, or 0.143 ohm. This added to the anode resistance of 1.8 ohms gives a total resistance of 1.943 ohms.

If now, after connecting the rectifier, it is found that because of the good condition of the paint coating 10 volts will deliver only 4 amperes, the actual resistance of the circuit will be $\frac{E}{I} = \frac{10}{4}$ or 2.5 ohms. This means that the paint coating has a resistance of 2.5-1.943, or 0.557 ohms. Therefore, of the 10 volts delivered by the rectifier 4×1.943, or 7.77 volts are used in overcoming the resistance of the water in the tank and the resistance of the line and 2.23 volts in overcoming the resistance of the coating. This pressure of 2.3 volts is too high to be concentrated across the paint film, as it will cause blistering and ultimate failure. To limit this to one volt the current must be limited to $\frac{E}{R} = \frac{1}{0.557}$, or 1.8 amperes. The corresponding rectifier voltage will be $E = IR$ where $R = 2.5$, the tested resistance of the circuit. Therefore $E = 1.8 \times 2.5$, or 4.5 volts.

Platinum Anodes

Where platinum electrodes are used Eq. B is inapplicable because of the indestructible character of the material, and a balance between E and L is now determined by economic considerations. Eq. A must also be modified, as the log factor for the small diameter wire now becomes about 4 instead of 2.5. This makes $EL = \frac{0.048\,iA}{1000}\,\rho$ (Eq. Ap

Taking the same values of i, A and ρ as before, we have for the three cases under consideration

$EL = 1080$ for $\rho = 900$
$EL = 3600$ for $\rho = 3000$
$EL = 10800$ for $\rho = 9000$

As platinum wire of 1/32-inch diameter, (about as small a wire as can be considered for mechanical reasons) at $80 per ounce, is worth about $8.70 per foot, it is evident that consideration should be given to the economic aspects of the problem because the annual charge on the installation costs increase with the length of wire while the power costs are proportional to the operating voltage. Theoretically the minimum annual cost will be where these two variables are equal, and our solution should attempt to determine that point

If we take 8.7 L dollars as the cost of the anode installation and r as the interest and depreciation rate on it we have 8.7 Lr as the annual charges on the installation.

With a power rate of p dollars per kwh, the annual charge for power, assuming a rectifier efficiency of 60 percent, will be $\frac{EIp \times 24 \times 365}{.60 \times 1000} = 14.60\ EIp$ dollars. Equating these two costs, we have

$$8.7Lr = 14.6EIp \text{ or}$$
$$\frac{E}{L} = \frac{8.7\,r}{14.6\,Ip}$$

Taking $r = 0.08$, $p = 0.01$, and $I = 25$ as in the design under consideration, we have

$$\frac{E}{L} = \frac{8.7 \times 0.08}{14.6 \times 25 \times 0.01} = 0.19 \text{ or } E = 0.19\,L$$

For $p = 900$, $EL = 1080$, or $E = \frac{1080}{L} = 0.19L$, or $19L^2 = 1080$

This gives

$$L = 75.5 \text{ and } E = 14.3$$

In like manner where

$$\rho = 3000 \quad L = 138 \text{ and } E = 21.7$$
$$\rho = 9000 \quad L = 239 \text{ and } E = 45.3$$

The most appropriate voltage for the bowl can also be used on the stand pipe electrode, although a resistor to limit the current may be desirable as previously pointed out.

DISCUSSION

Comment by Oliver Osborn, The Dow Chemical Company, Freeport, Texas:

In regard to the effect of anode grouping mutual interference it should be pointed out that lead resistance is very critical when dealing with low resistivity media. For example, when considering a group of say ten magnesium anodes in sea water connected to a common lead, the resistance of the lead can be only a small percentage of the total circuit resistance if the theoretical formulas are to hold. In this case 10 feet of No. 10 wire could produce a decrease in current output of as much as 25 percent from calculated values:

Authors' Reply:

Lead resistance under the extreme conditions described by Mr. Osborn would, of course, have to be taken into consideration. However, it is not apparent that lead resistance will have any influence on the mutual shielding or interference of grouped electrodes, or in any way change the figures given in Tables II to V which are based solely on the resistance of the anodes to remote ground. Where galvanic anodes are concerned the current output will be influenced more by lead resistance than where higher voltage rectifiers are in service. In any event it should be a simple matter to calculate this factor and select sizes and lengths of leads accordingly.

Question by W. P. Noser, Humble Pipe Line Co., Houston, Texas:

The resistivity method described as the four pin method apparently shows the use of two current pins and two half-cell electrodes as the potential pins. If this is true was there any initial potential difference between the half-cell electrodes when placed in the earth?

Authors' Reply:

When using direct current, galvanic potentials between potential electrodes are eliminated by averaging the observed values obtained by passing the current between the current electrodes first in one direction and then in the other. In the Gish-Rooney method a periodic or alternating current is used, having a frequency of about 30 cycles per second. This effectively eliminates the effects of both galvanic and stray railway currents.

Question by H. H. Uhlig, Massachusetts Institute of Technology, Cambridge, Mass.:

How important is polarization in the application of these equations? Since polarization is encountered in all practical systems is not the next logical step the addition of polarization terms to the resistance equations?

Authors' Reply:

Dr. Uhlig's question is, of course, a pertinent one. The importance of polarization in the application of these equations will depend largely upon the magnitude of the operating voltages. Where rectifiers operating at 10 volts or more are used the polarization potential of the circuit is relatively small and will affect only slightly the calculated results. With galvanic electrodes it is customary to base designs on the net or resultant voltage to be expected. As polarization is a variable factor, changing with time and other conditions, it is not apparent how a simple or direct modification of the resistance equations can be made to include it.

Comment by Lyle R. Sheppard, Shell Pipe Line Corp., Houston, Texas:

It should be noted that both Dwight's and Sheppard's formulas for anode resistance take only size, shape and position of anode into consideration. The chemical composition of the anode or the environmental surrounding it are *not* considered. Hence, polarization does not enter into the calculations.

The only way polarization can have an effect is in the method of measurement. If direct current is used, the measured "apparent" resistance will increase with increased applied voltage until a maximum "apparent" resistance is reached. This voltage point possibly is the point at which rapid hydrogen evolution begins, because measured resistance becomes less with increased voltage beyond this point.

A Method of Selecting Protective Coatings For Offshore Drilling Structures*

By JACK P. BARRETT

THE PETROLEUM industry has been engaged in the past few years in the production of petroleum from the continental shelf in the Gulf of Mexico.

The wells are as far as ten miles from shore, making the operations true marine ventures.

Figure 1 shows one of two typical types of structures. This structure is a complete unit which provides living quarters as well as working space for all operations. Figure 2 shows another type of structure in which a converted LST is used for living quarters and storage while the platform has space for only the drilling equipment. Total cost of these structures, as pictured, was close to $1,000,000. Besides the structure, there must be stand-by boats, crew boats, and supply boats. The corrosion problem is one of marine exposure in which the equipment is constantly exposed to the extremely corrosive salt air and water.

The cost of all this equipment, plus the production equipment such as tanks, treater, etc., make a corrosion control program imperative.

The use of protective organic coatings for corrosion prevention for some of this equipment is highly desirable.

Conditions of Exposure

There are three conditions of exposure that the coatings will have to withstand; atmospheric, spray or tidal zone, and continuously submerged.

For atmospheric exposure, the material would have to withstand continuous exposure to a moist, heavily salt laden air and extreme conditions of sunlight. Equipment to be protected in this exposure zone will include part of the platform, derrick, drilling and production equipment.

The second exposure condition would be in the spray or tidal zone where the metal is alternately wet and dry. This is considered to be the most severe exposure condition. The main structural members of the platform plus the well casing are in this zone.

The third exposure is that part of the structure which is continuously submerged. The supporting piling for the platform plus other structural parts are exposed to this condition.

General Requirements of Material

The requirements of a coating for this service, though related to ship coating requirements, are somewhat different.

The structure itself is partially fabricated on shore and barged to location where it is erected. This erection involves driving piling, welding piling and other sections, and handling.

For this service a coating should have high adhesion, flexibility, resistance to abrasion and be somewhat heat resistant. The coating should lend itself to easy patch application, as field patching is possible only under adverse conditions in salt and moisture laden air.

Besides the marine atmosphere, certain sections will be exposed to fuel oil, highly alkaline mud and well fluids.

The submerged section is under cathodic protection; therefore, the coating must be able to withstand

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Abstract

A general outline of the principal conditions of exposure encountered in marine operations associated with petroleum production. The high cost of marine or offshore wells makes a corrosion control program imperative. A major part of this program is the use of organic protective coatings. This type of application is relatively new for most paint manufacturers and consequently a laboratory testing program was set up to evaluate protective coatings. To further verify the laboratory results, panels coated with the various painting systems were exposed at a marine location in the Gulf Coast. A laboratory testing program is described in which quantitative measurements of the film characteristics are made. By using the moisture vapor transmission salt spray and adhesion tests, a laboratory rating is calculated by which coatings are rejected or further tested in the field. The better coatings together with some of the unsuitable ones were exposed on test panels at a marine test station in the atmospheric, tidal or splash zone and totally submerged. Correlation between the laboratory and the marine test station exposure is given as ninety-one percent. Some thirty systems have been tested to date and approximately sixty percent were totally unsuited for these exposure conditions. Twenty percent were of doubtful value leaving twenty percent that could be used with more or less effectiveness. It is concluded that petroleum companies engaged in this work should outline a standard test program to be used in testing the materials submitted for the various exposures encountered.

*A paper presented at the Sixth Annual Conference, National Association of Corrosion Engineers, St. Louis, Mo., April 4-7, 1950.

the electrolysis associated with cathodic protection plus the alkaline condition formed by electrolysis.

The tender vessels are anchored for long periods at the well site and, therefore, the coating requirements are slightly different from a normal seagoing vessel. A sacrifice in antifouling can be made in favor of extra corrosion protection.

It has been the practice in some companies to refer the coating problems to a reliable or well-known manufacturer of such materials and use the materials that were submitted. Another widely used method of selection of coatings is to check advertising literature and then select the material of that company which makes the best claim for the exposure considered. As the use of exposures herein described are somewhat new and different from other exposures encountered, this particular type of application is new for most paint manufacturers and consequently there is not too much experience on materials for this service.

Figure 3 shows the need for laboratory testing of coatings for this service. These five panels represent materials which, based on past marine use, were recommended for the above described exposure. Two of the coating systems from two of the companies and one system from the third company failed after four months' exposure to marine conditions. These panels were exposed in the tidal zone. All tests were conducted at Stanolind's Gulf Coast test site. It should be noted that the conditions of exposure were outlined to the manufacturer and his recommended system for that condition was used.

From this, it is obvious that a testing program is necessary to obtain the best material available for further field testing and actual use. The coating manufacturers were very helpful in recommending and supplying materials for these evaluations.

A laboratory program supplemented by field testing was initiated to evaluate the various coating materials offered for this service. Stanolind's laboratory tests are not used for final evaluation of the material. The object of the laboratory test program is to limit the more expensive field trials to only the best of the various materials available. To accomplish this, certain characteristics of a film or system that can be quantitatively measured and which are believed to be most important to the proper functioning of the system are selected. Standard tests only are used; no "trick" tests are employed.

Laboratory Testing Program

Moisture Vapor Transmission (MVT)

All films are tested for moisture vapor transmission in an atmospheric control cabinet as designed by C. A. Southwick. In this test the paint film is used as a barrier to seal a container of anyhydrous calcium chloride which is exposed to an atmosphere of 100° F at a relative humidty of 95 per cent.

Preparation of the sample is relatively quick and simple. Normally the coating system is sprayed on a plain glass surface and peeled off. However in using this method it was difficult to obtain representative films of sufficient size on some coatings. It is standard practice now to spray the system on a six-inch diameter smooth finish qualitative filter paper. The paint films so prepared and cured are placed in an aluminum pan above approximately 100 gms. of anhydrous calcium chloride. The edges of the film rest on the shoulders of the pan and it does not contact the salt. A templet of approximately ½-inch smaller diameter than the specimen is placed over the sample and melted wax is poured between the templet and edge of the pan to form a moisture tight seal. After the wax has cooled the templet is removed and the

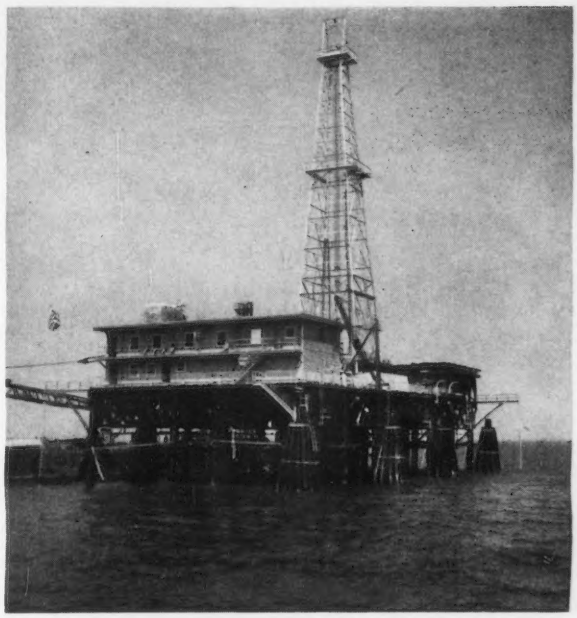

Figure 1—Offshore structure as complete unit.

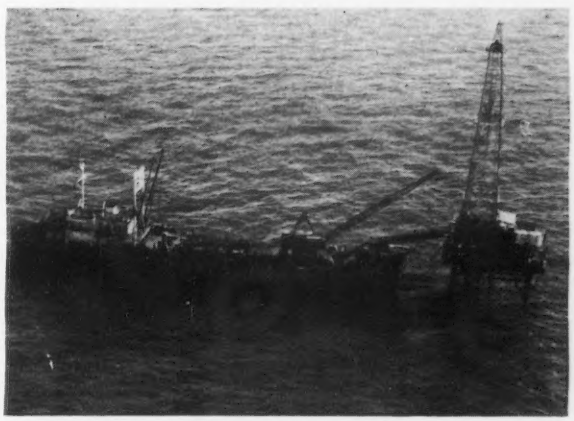

Figure 2—Offshore structure in which a barge provides living quarters and storage space for operations.

Figure 3—Results of panels exposed in the tidal range of the Gulf Coast, showing unsuitability of previously used marine coatings.

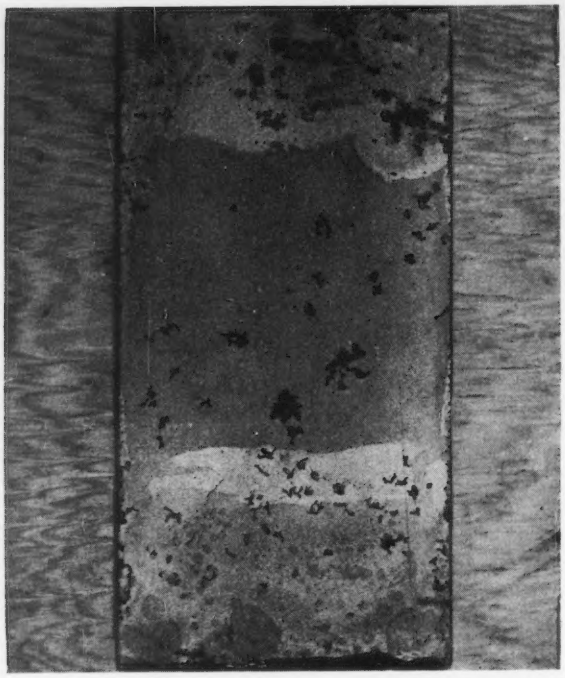

Figure 4—Panel that has been stripped of coating showing corrosion spots. Failure of material was undetected by visual and 20 X magnification examination.

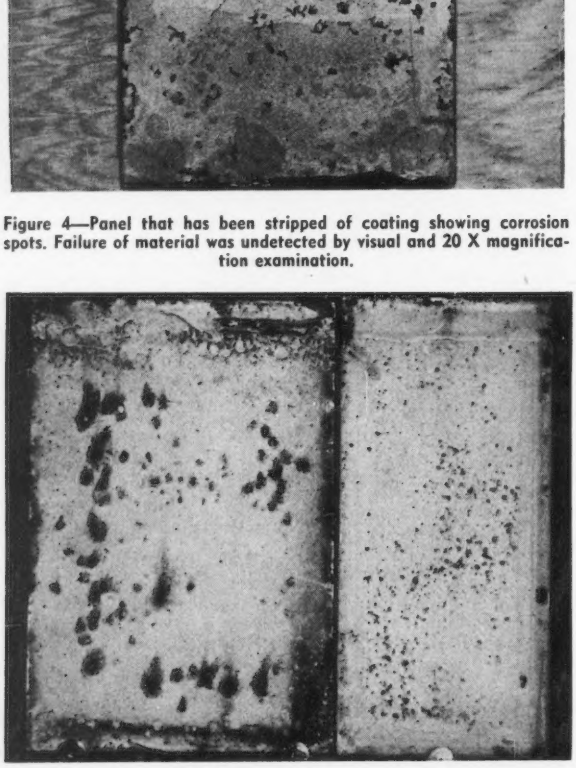

Figure 5—Panel on right exposed in salt spray cabinet four months. Other panel exposed four months in tidal range on Gulf Coast. Note close correlation between artificial and actual exposure.

specimen is ready for test. The actual test consists of placing the test specimen and dish in the humidity cabinet for twenty-four hours. The dish is then removed and placed in a desiccator for four hours. At the end of this conditioning cycle the test dish is weighed on an analytical balance. The test dish is again placed in the humidity cabinet and allowed to remain for sixty-eight hours then removed, placed in the desiccator for four hours and again weighed. The difference in the two weights in grams, when multiplied by 1.71, is the grams of moisture-vapor transmitted by 100 square inches of the sample per twenty-four hours at the conditions of test.

This test gives a quantitative value in grams per unit area for the amount of moisture that passes through the film. Since a protective coating is to serve as an impervious envelope between the material to be protected and its corrosive environment, it is obvious that the greater the moisture vapor transmission rate, i.e., the more moisture passing through the film the less desirable the coating.

Adhesion

Another important factor in a coating system is the adhesion of a coating to the base metal. There are various methods used to measure this property, most of which are based on a knife method. This method consists of using a knife and by some means measuring the amount of applied force necessary to remove the coating from a prepared panel. We are using for this test the Shear Hardness Attachment on a Taber Abraser.

The coating system is built up on a metal panel with a slightly polished surface. After the manufacturer's recommended drying time + 72 hours the panels are tested. The first step consists of cutting, by means of a special roller knife attachment, a strip around the panel of the same width as the test knife which is approximately ¼-inch wide. This cut eliminates the cohesion between test strip and main film body from being measured. The test knife is then substituted in the jig for the roller knife. The knife is forced through the coating to prevent the hardness of the coating from interfering with measurement. Sufficient weight is applied to the lever arm of the apparatus until the coating is removed when the panel is rotated with the knife in place.

Although we do not obtain absolute values, we do obtain reproducible relative results. The relative values so obtained are sufficient to make comparative evaluations.

Salt Spray

For laboratory exposure tests, a standard salt spray cabinet is used using a 20 percent sodium chloride solution.

The examination of the panels exposed in the salt spray is made by visual, microscopic and electrical measurements. A modification of the well-known resistance measurement for determining film continuity is used as a major inspection method. A contact wire is soldered to the metal panel prior to painting. After the coating system is built up on the panel, the resistance between the panel and bare metal is measured. This is done by immersing the panel in salt water and measuring the resistance between it and a bare metal electrode using an ohm meter. If the film is continuous there will, of course, be an infinite resistance. Only panels having continuous films are exposed to the salt spray.

At one week intervals the panels are removed, washed with tap water, and examined visually for signs of failure. If no visual failure is evident, one lead of the ohm meter is attached to the contact wire on the panel. The other lead is attached to a small ⅛-inch swab soaked in salt water and then moved across the surface of the panel. Any decrease in re-

sistance is noted and the area is examined under the microscope.

This method enables us to detect the slightest failure of a film long before the failure is visible. In fact, some minute pin-holding has been detected by this method and active corrosion found on panels that would, by ordinary inspection, be classed as satisfactory.

One system (Figure 4) was exposed and by visual inspection and examination with low (20X) magnification, no failure was noted. By use of the resistance measurement as described, several isolated pin holes were detected. The coating was stripped from the panel and rather widespread corroded areas were noted.

Although some doubt on the value of salt spray testing exists, we feel that for the purpose intended, it is a sound and reliable test. In fact, in some cases it is too close to actual conditions to allow accelerated testing. Figure 5 shows two panels; the one on the right was exposed four months in the salt spray cabinet, while the other was exposed four months in the tidal range at our marine test station.

It can be noted that the type of failure, as well as the extent of failure, is the same. Where this close correlation has been noted on several sets of panels, this particular system checked almost exactly.

Miscellaneous Tests

The abrasion resistance is measured by use of the Tabor instrument using CS 17 Calibrase wheels with a 1000-gram load. The coating is abraded until the base metal is exposed. Abrasion resistance is reported in wear cycles per mil (1/1000″) of coating thickness.

This test is of major importance from some service and is run on all systems that would be subjected to mechanical wear.

Standard mandrel flexibility tests are made on each system and various items on application difficulties or advantages are noted.

All coatings are applied over sandblasted surfaces. The method of application as recommended by the manufacturer is strictly adhered to as are thinning ratios, drying time, film thickness, etc.

Method of Laboratory Rating

The laboratory tests are used to screen the coatings in order that only the most promising will be exposed at our marine test station. In order to evaluate the coatings on the basis of the laboratory tests the coating systems were scored and rated as follows:

The results obtained on the MVT test were rated in numerical order, the lowest value being designated as number one.

The days to failure in the salt spray were noted and also rated in numerical order with the longest time to failure being rated as one. As this test more closely approaches actual exposure, it is assumed to be three times as important as the other tests; that is, the rating is multiplied by three.

The values obtained on the adhesion test were listed and rated in numerical order, the highest value being designated as one.

All these ratings were then added and a final score or total was obtained. The lower the total, the better the coating. On this basis the coatings were listed in order of performance.

At the present time it is planned that if the score obtained in laboratory tests by a coating exceeds thirty, no further testing of this system is necessary, that is it is not worthy of field exposure and is unsuited for use.

It should be noted that the above rating system was used only on the first group of materials tested. It is apparent that if a long program of testing was followed this system would be very inconvenient to use because it is dependent upon a group rating. In order to make the rating of any one material system more independent of its own numerical rate as compared to another system the rating method has been modified. The laboratory rating is caluculated as being equal to 3 X salt spray performance factor plus adhesion factor + 5 X MVT value.

Based on the results of a one and one-half year test program, ten months of life in the salt spray is indicative of a suitable coating for marine exposure. The following key is used to rate the salt spray performance:

Months to Failure	Salt Spray Performance Factor
10	1
9	2
8	3
7	4
6	5
5	6
4	7
3	8
2	9
1	10

The adhesion factor is calculated as follows:

$$\text{Adhesion Factor} = \frac{2000}{\text{Adhesion Value}}$$

The value obtained on the moisture vapor transmission test is multiplied by a factor of 5.

This system of rating, though slightly different

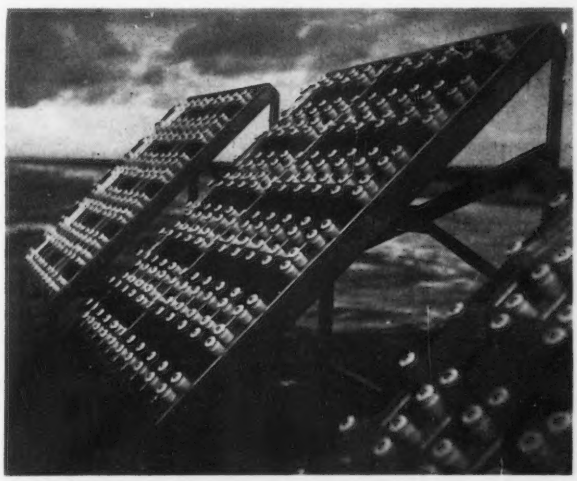

Figure 6—Close up of atmospheric exposure racks showing method of panel attachment.

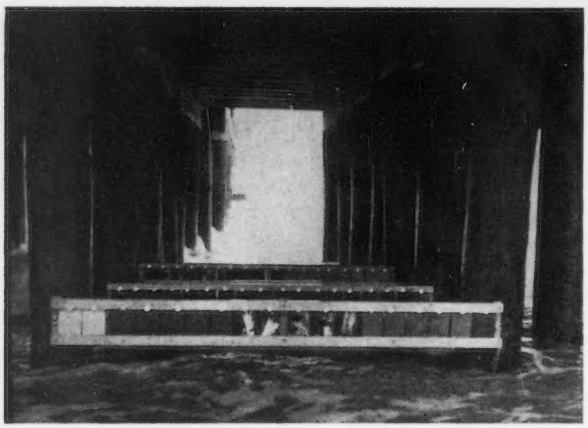

Figure 7—General view of tidal range racks at approximately half-tide.

from the first method, gives the same relative rating when applied to the original group of materials as was originally obtained.

Field Testing and Correlation With Laboratory Results

To further check the performance of the coating, test panels of those systems passing the laboratory tests are prepared and exposed at our High Island test station on the Texas Gulf Coast. Figure 6 shows the atmospheric racks. The coatings for the tidal zone are exposed in the racks shown in Figure 7. The systems for continuous submerged conditions are tested in a floating type rack.

These panels are inspected every month to check their resistance to the exposure conditions.

Of primary interest to anyone engaged in a laboratory testing program, is the correlation between laboratory and field tests. It is felt that for the exposure intended, laboratory tests outlined give very good correlation. A group of coatings classed by laboratory tests as unsuitable were exposed at the High Island racks to verify the laboratory rating system. Table I shows the grading made on the basis of laboratory tests prior to field exposure for thirteen systems. The left side of this table gives the grading of the same systems based on actual exposure. It can be noted that systems with a score of over thirty failed in four months' exposure or less.

TABLE I

Results of Laboratory Rating of a Group of Coating Systems and Correlation with Actual Exposure Results

Coating System	Laboratory Score	Laboratory Rating	Performance Rating Based On Test Exposure*
A	21	1	1
B	27	2	2
C	29	3	3
D	32	4	..
E	34	5	..
F	37	6	..
G	38	7	..
H	39	8	..
I	45	9	..
J	45	10	..
K	50	11	..
L	55	12	..
M	74	13	..

* No rating is given if failure occurred in 4 months or less.

Using the tests described and scoring the coatings as shown in Table I, we have obtained 92 percent correlation between the laboratory and field panel exposure tests on which we have complete data. Table I does not include all of the coatings used in computing the 92 percent correlation value.

It is interesting to note that using our present standards, approximately 75 percent of all the coatings submitted for test would not be suitable for field testing.

Value of Surface Treatment

Wash primers and surface pretreatments for surface preparations are well-known and widely used. It has been noted that the systems which give the best service are those which use a pretreatment. Figure 8 shows the results of one test in which a coating system was applied as recommended both with and without a pretreatment. The panel without the pretreatment failed after one week's exposure in the salt spray cabinet. The pretreated material after seven weeks' exposure, while not in good condition, definitely was better than the panel without pretreatment.

In the investigation of pretreatments, premature failure of the system due to excess free acid in the pretreatment has been encountered. In some cases the film failed during the curing time and prior to exposure.

Value of Laboratory Program

It is to be emphasized that the laboratory evaluation of a coating material or system cannot and is not intended to provide a complete answer to the question of which coating should be used.

The most to be hoped for in laboratory testing conducted by Stanolind is to eliminate the large number of sub par materials and to determine which materials should be field tested.

It is felt that laboratory expense can be justified by preventing one misselection of materials on one or two major jobs. As an example, the coating of one LST will involve approximately $5000 in materials on the hull alone. This cost, plus dry docking charges and labor, will run the cost to well over $10,000. Figure 9 shows a vessel of this type after receiving such a job.

A coatings laboratory such as described will cost approximately $4000 for the physical equipment and installation. Counting the cost of labor and the equipment, the first year's operation would be approximately $9000 or about the cost of coating one vessel. A laboratory evaluation will prevent the use of materials similar to that shown in Figure 10. This material is a standard, commercially available coating for marine use. These panels failed in five months' exposure on the Gulf Coast.

General Conclusions

By way of conclusions, it is felt that:

1. Various standard tests such as the MVT, adhesion and salt spray test can be relied on to classify or rate coating systems for marine exposure.
2. These tests, when each is considered as a part of the total rating, will give good correlation to actual exposure conditions as outlined.

3. Laboratory testing, although costly, can be justified from an economic standpoint.
4. The oil industry should develop and use a simple and standard testing program, not only for marine coatings, but for other organic protective coatings.
5. The manufacturers of the various coating materials should give more careful consideration to the exposure conditions prior to their submittal of coating recommendations and materials and should work with the industry to provide satisfactory materials for this service.

Acknowledgment is made to Mr. R. H. Goodnight of the Stanolind Laboratory who performed all the tests and made all panel preparations in this testing program. Appreciation is also expressed to Stanolind Oil and Gas Company for permission to release and present this material.

DISCUSSION

Question by G. G. Sward, National Paint, Varnish and Lacquer Association, Washington, D. C.:
How did you support the films for permeability?

Author's Reply:
The film for this test are applied over 6-inch diameter coarse qualitative filter paper. There may be objections to the use of such a support, but we feel results of the tests are sufficiently accurate to allow comparison.

Question by L. D. Cook, Jr., Wyandotte Chemicals Corp., Wyandotte, Mich.:
From your investigation, what do you believe to be the effect of film thickness upon the durability of a coating system?

Tests of maintenance coating systems on steel in severe chemical plant atmospheres over a two-year period at Wyandotte, Michigan, have confirmed your findings that the wash prime coatings are excellent in reducing or preventing sub-film corrosion. Furthermore, it has been our experience that the durability of paint type coatings is greatly dependent upon the total film thickness. Films of less than .005 inch have usually yielded service lives of much less than one year in severe exterior chemical plant atmospheres, while films of .006 inch to .010 inch are in excellent condition after two years. This applies especially to the chlorinated rubber and vinyl type paints.

Author's Reply:
In the exposures with which we have experience, I believe the thickness has two main effects: First, the added thickness supplied by multiple coats reduces the incidence of holidays. The second effect is to increase film life by adding abrasion resistance.

Question by V. B. Volkening, Dow Chemical Company, Freeport, Texas:
Because the necessity of applying coatings under adverse conditions to offshore rigs was stressed, I would like to know what experimental work has been done

Figure 8—Panels coated with the same marine system. Panel on the right pretreated and exposed seven weeks. Panel on left, not pretreated, was exposed one week. Exposures were made in a salt spray cabinet.

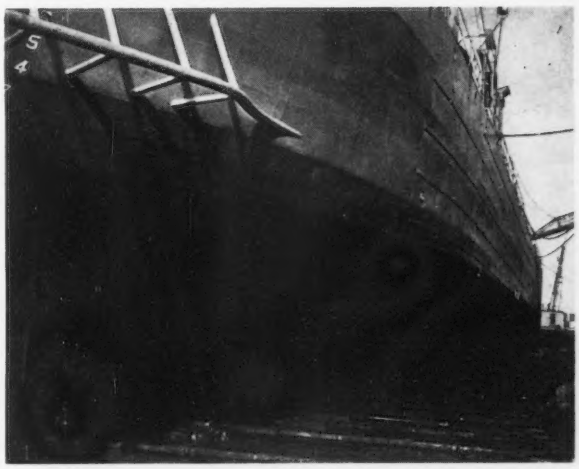

Figure 9—View of tender barge hull after coating job.

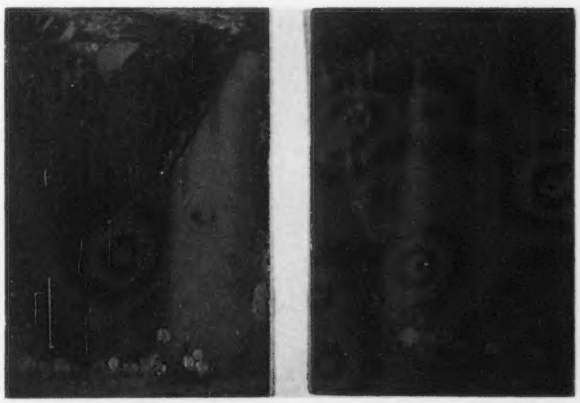

Figure 10—Results of exposure of proposed marine system. Exposure was for five months in tidal range on Gulf Coast.

in attempting to repair vinyl coatings in areas of failure directly on the drilling platforms.

Author's Reply:

We have had no experience in this type of repair work. However, one structure was painted with good results in a Gulf Coast shipyard under moderately poor conditions.

Question by C. C. Harvey, Ethyl Corp., Baton Rouge, La.:

1. Work done at Ethyl Corporation, Baton Rouge, La., in selection of coatings for chemical fume resistance closely parallels the efforts of Mr. Barrett. In these tests however it was found that coating life depended in a large measure on film thickness. Also, film permeability is known to depend to a large degree on film thickness. Since Mr. Barrett realized the importance of low permeability, how can the film thickness factor be relegated to minor importance in such tests?

2. What values of film permeability versus film thickness were actually obtained?

Author's Reply:

It should be pointed out first that in all our work to date, only complete systems have been tested. That is, a manufacturer's recommended system for a given exposure was tested rather than one company's primer, another's body coat, and possibly a third company's top coat. For this reason, in speaking of film thickness in connection with film permeability no definite conclusions can be made as we are comparing different systems.

The following values obtained on MVT tests demonstrate why no great emphasis is put on film thickness as an indication of permeability. All values listed are for vinyl systems.

Coating System	MVT Value (gm./100 in.²/24 Hrs.)	Thickness of Film (Mils)
A	2.825	4
B	2.429	4
C	1.592	5
D	2.900	5
E	1.542	6
F	2.608	6
G	1.104	6
H	1.686	6.5
I	1.400	9
J	1.258	10
K	2.110	13
L	0.942	22

If in testing we used a given formulation to determine the relation of film thickness to film permeability, we might find a very definite relationship. However, from a practical standpoint there would be an economic limit to the thickness of a coating which could be applied, assuming that thickness was dependent upon the number of coats.

Comment by E. R. Stauffacher, Southern California Edison Co., Los Angeles, Cal.:

The author is to be congratulated in his clear presentation of a plan of test procedure to determine the most suitable and durable protective coating for his conditions. I agree with him that it does not take a great amount of time to determine the poorest coatings but it does take considerable time to determine which are the best and most suitable.

It would be of interest to know what types of coatings were tested—not the exact formulations, but whether they were of the oleoresinous, alkyd resin, or vinyl type. A general classification would be of considerable value if the author is at liberty to divulge which classification has shown the most promising results up to this time.

Author's Reply:

By far the most systems submitted for tests were the vinyl type materials. We did test some chlorinated rubber formulations as well as the oleoresinous and alkyd type materials. Of the coatings we tested, the vinyl type coatings as a class gave the best results.

Comment by H. E. Waldrip, Gulf Oil Corp., Houston, Texas:

First I wish to compliment Mr. Barrett on the presentation of a very fine paper.

I had the pleasure of visiting the marine location referred to in this paper and the opportunity of seeing many of the panels just discussed.

We have been carrying on somewhat the same type of testing as Mr. Barrett, but in the testing of vinyls, in addition to the exposures mentioned, we submitted panels to an accelerated test in West Texas. The panels were placed in the vapor space of an ethylene glycol dehydrator under 270 psi for 60 days. We feel that this is an accelerated test comparable to the vapor phase of sour crude stock tanks. After the 60 days' exposure, half the coatings were complete failures; only one was in perfect condition. The balance ranged from poor to good.

While vinyls have very good chemical resistant properties the user should be cautioned that all vinyl coatings are not the same and some kind of testing program should be undertaken to insure securing a product that ranks with the best.

Author's Reply:

In connection with Mr. Waldrip's remarks on sulfide resistant coatings, it might be of interest to mention the work we are doing on coatings for this service.

The systems are tested for adhesion, flexibility, and MVT rate in the same manner as the marine system. Also, an extraction test using kerosene is used to check the effect of oil on the coating.

To test the resistance of the film to hydrogen sulfide gas, a test box has been designed which exposes the material to an air-hydrogen sulfide atmosphere. The panels are placed in the box in a plane parallel to the floor. A mixture of 3% air, 400 ppm H_2S, with the remaining gas nitrogen, is fed into the box at a rate of ½ cubic foot per hour. Every hour a stream of nitrogen saturated with water at 150° F is allowed to feed into the box for two seconds. This moisture in the nitrogen is sufficient to form a film of condensate on the panels. This condensate keeps the panels wet from 20 to 30 minutes of each hour. Tests for film breakdown are made using a continuity meter as well as by visual and microscopic examination.

It is planned that coatings which are classified as satisfactory in these tests will be field tested by exposure in sour crude tanks. No correlation between laboratory and field test has yet been attempted.

I wish to emphasize Mr. Waldrip's remark that all vinyl coatings are not the same. It is extremely important that several different manufacturers' materials be obtained and not base the results of a testing program on a "representative" material.

Comment by R. C. Buchan, Humble Oil & Refining Co., Houston, Texas:

Sand blasting steel surfaces prior to coating is desirable only if the coating has a long life, that is, 5 to 10 years; otherwise, it is uneconomical. Present practices on structures that appear feasible include the use of 1) "pipe line" type doping and wrapping and 2) semi-hardening, grease-like coatings applied over machine-cleaned or wire-brushed surfaces.

Progress Report

The Use of Cathodic Protection In Conjunction With Paint Coatings*

By W. L. CROSBY*

THE CONSOLIDATED Edison Company of New York, Inc., has several hundred transformers and network protectors installed in manholes where they are subject to complete or partial immersion in salt water at high tide. As a result, it is confronted with a situation where the service life of these units between overhauls is being governed by the corrosion of the exterior surfaces of their steel tanks rather than by deterioration of the winding insulation, bushings or other components more intimately associated with their main service function. Figure 1 shows one of these transformers that has been removed from service and delivered to the Company shop for overhaul.

Corrosion of the tank is plainly visible, particularly over the lower part of the transformer. The high water mark indicates that the lower third of this unit had been immersed. Figure 2 shows a close-up of the corrosion on the bottom of the cooling tubes of another transformer. These tubes are filled with insulating oil which circulates through the transformer windings, serving the dual purposes of cooling the windings and of insulating them from the case. It is evident that any major loss of this oil through holes in the tank or tubes caused by corrosion would soon lead to a failure of the transformer. Periodic re-painting or inspections of the extent of the corrosion of these tanks and tubes while the transformers are in service is frequently impossible because, owing to the congested conditions under the streets in New York City, the transformers are installed in manholes with but a few inches of clearance on all sides.

This corrosion problem is in many respects similar to that encountered by the maritime industry with the accelerating factors of sewage, oil, salt and other refuse from city streets. The fact that the transformer cases, and consequently any protective coatings applied to them, normally attain temperatures of 140 or 150 degrees Fahrenheit for extended periods daily makes the problem more difficult.

The first step in tackling this problem was obviously to select the best available paint coating system from a corrosion protection standpoint that could be applied readily. This selection has involved the testing of over 100 different paint coating systems in the Consolidated Edison laboratory.

The test procedure used was designed to simulate, as closely as practicable, the corrosion conditions encountered in the field, and the results obtained on earlier tests have been completely substantiated by exposure of test panels in a tidal manhole. The test

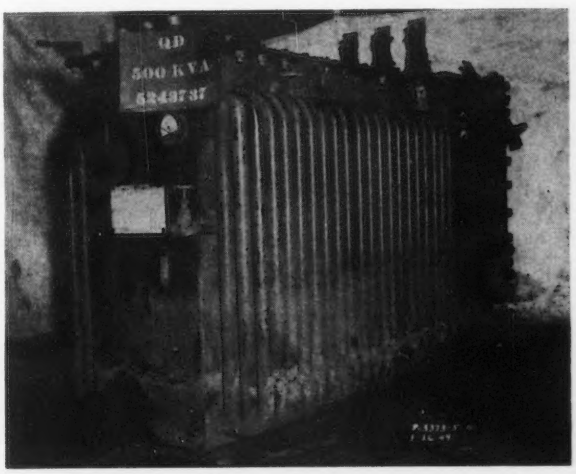

Figure 1—Typical case of transformer corrosion. Distribution transformer as returned from service for overhaul.

★A paper presented at the Sixth Annual Conference, National Association of Corrosion Engineers, St. Louis, Mo., April 4-7, 1950.

* Test Bureau, Consolidated Edison Co. of N. Y., Inc., New York, N. Y.

Abstract

Attempts to mitigate corrosion of steel tanks housing hundreds of transformers and network protectors have led to two main investigations: first, the selection of the best available paint coating system from a corrosion protection standpoint that can readily be applied, and second, the determination of the feasibility of applying cathodic protection in conjunction with this coating. The selection of the best paint coating system has involved laboratory testing of approximately one hundred different systems under conditions simulating those encountered in service. As a result, the present coating system consists of three coats of an asphalt base paint. Recently, two plastic coating systems, both vinyls, have shown up equally good on test but application difficulties have have prevented their adoption at present. The study of the feasibility of applying cathodic protection in conjunction with the protective coating is still in its initial phases although it has been going on for over a year. To date, the investigation has considered the following phases: a) Choice of a suitable electrode. b) Effect of cathodic currents from magnesium electrodes on four different paint coatings. c) Effect of electrolytes containing various mixtures of salt and fresh waters. d) Effect of magnitude of cathodic current. e) Actual field installation of a magnesium electrode in a tidal transformer manhole. Tests on four different protective coatings, using a magnesium electrode and a straight sea (East River) water electrolyte with no control of the cathodic current, gave widely divergent results. Tests made on the standard asphalt base coating with electrolytes consisting of all East River water, equal parts of East River and tap waters, and one part of East River water to three parts of tap water showed no major differences although the resultant cathodic currents were roughly proportional to the amount of East River water in the electrolyte. Tests made on the standard coating with cathodic currents maintained at 1.0 and 0.5 milliampere for comparison with the original test at 47-67 milliamperes indicate that deterioration of the coating around the window starts within 4 days and that the rate of deterioration is roughly proportional to the cathodic current in the ranges considered. However, at both lower currents, rusting was observed on the uncoated sections whereas none was observed at the highest current. The rapid and almost complete removal of the protective coating was confirmed by a trial installation of a magnesium electrode in a tidal transformer manhole in the Coney Island section of Brooklyn. Although indications to date are that cathodic currents of sufficient magnitude to prevent corrosion at breaks in protective coating surfaces cause deterioration of the coating, it is planned to investigate other electrode materials, and the effect of holding the galvanic potential below the hydrogen over-voltage point.

Figure 2—Close up of bottoms of corroded cooling tubes on a distribution transformer.

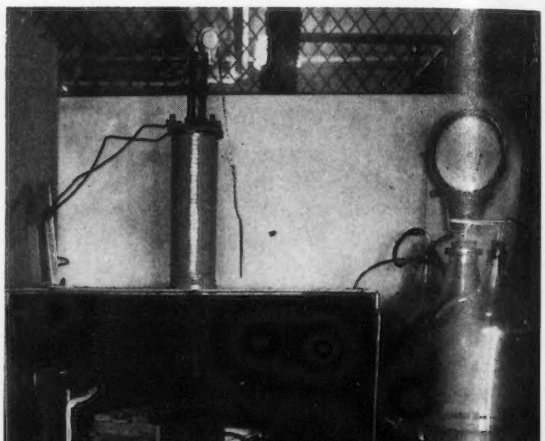

Figure 3—Tide water paint test set-up.

consisted essentially in the alternate immersion in salt water of steel test panels, coated with the paints to be tested, the whole test being conducted in a chamber maintained at 140 to 150 degrees Fahrenheit. As shown pictorially in Figure 3, steel test panels, 6 by 2½ by ⅛ inches, coated with the paints to be tested, are suspended in a shallow tank. A one percent salt (NaCl) solution is then introduced into this tank at a controlled rate which allows the solution level to rise to within one inch of the top of the specimens in 12 hours. The solution is then allowed to drain gradually out of the tank during the next 12 hours, and the cycle repeated until failure of the coating occurs. After an initial period of nine days during which periodic measurements of electrical insulation resistance are made, a cut in the form of a cross exposing the bare metal of the test panel is made in the center of one face of each test panel. This cut is made for the dual purposes of accelerating the corrosion and simulating scratches that invariably occur in the paint coatings while the transformers are being transported and installed in manholes. Periodic observations are made of the amount of rusting, blistering of the paint, and the general appearance of the coating, on each panel. To date, very few paint coating systems have maintained a good appearance and afforded good protection for 150 days of this test.

Based on this test, the company standardized on an asphalt base paint coating system several years ago. Recently, two plastic coating systems, both vinyls, have shown up well on test.

The transformer tank and tube surfaces are grit-blasted and three coats of the asphalt base paint flowed-on. Spray or brush coating is not used be-

cause of difficulties in applying the coating on the back of the cooling tubes and between tubes, especially on the larger units where there are several layers of tubes from the tank outward.

After all tests on paint systems, no coating has been found that will provide adequate corrosion protection under the company's particular service conditions for a period anywhere near the electrical life of the transformer. For this reason, cathodic protection is being considered as an additional means of protection to supplement that of the paint coatings.

First applications of cathodic protection to transformers in manholes were instigated and supervised by L. J. Gorman, to whom the author is indebted for the material from which the following case history of those applications was prepared.

Initial Application in Three Manholes

In 1937, initial application of cathodic protection to transformers was made in three tidewater manholes in which the transformers are completely submerged at all times. These first installations consisted of iron pipe anodes placed in the bottom of the manholes and connected to small rectifiers. This system was tried for approximately one year and, although the results were promising from a protection standpoint, the necessity of providing rectifiers that would operate under salt water, and the amount of maintenance and adjustment required for these rectifiers, led to the trial of zinc anodes in place of the iron pipe and rectifiers.

Zinc anodes were first installed in 1938 and seemed to function satisfactorily for a short time. However, after about two months, an insulating coating formed on the zinc anodes practically stopping the flow of current between the anode and the transformer case. The anodes were replaced at one-to-two-month intervals, but it was noted that deposits were appearing on the transformer case in spots which upon removal disclosed some pitting underneath. Because this was not considered sufficient protection, the use of zinc anodes was discontinued in 1942.

In 1945, initial trials of magnesium anodes were made and, although it was noted that the magnesium anode system tended to remove the paint from the transformers, as was the case to a lesser extent with the zinc anodes, the installations were extended until 22 manholes were equipped with magnesium anodes. In one of these installations on Neptune Avenue in the Coney Island section of Brooklyn, the transformers have been under cathodic protection continuously since 1946. In this three-year period, 88 pounds of magnesium have been consumed and the paint has been entirely removed from the transformers but there is no evidence of corrosion on the transformer cases. Figure 4 shows the appearance of these anodes after three years of service together with pertinent data on their performance.

With this background of field experience, it was decided to conduct investigations in the laboratory to find either a paint coating that would not be affected by this form of cathodic protection, or a satisfactory cathodic protection system that would not affect the paint coating. This laboratory investigation

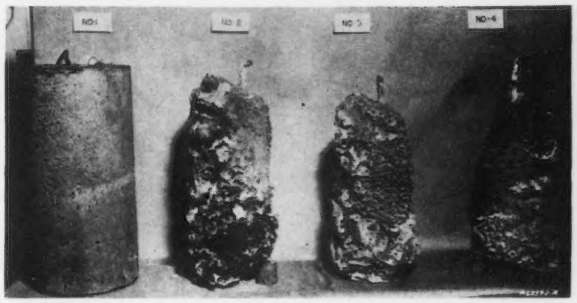

Figure 4—Magnesium anodes after three years' service in transformer manhole. (No. 1 anode unused.)

Initial weight, 3 anodes, lb.	150
Loss in wt. 3 anodes, lb.	88
In service, days	1084
Average current, amp.	1.38
Ampere hours	34,800
Ampere Hr/lb.	395

has been conducted, intermittently, for over a year and has substantially reproduced the results experienced in the field while yielding other interesting results which will be discussed in detail later.

While no satisfactory solution to the problem has been obtained, the laboratory investigation is being continued and the results are submitted here in the hope they will stimulate some discussion.

To date, the investigation is considering the following phases:

1) Effect of cathodic currents from magnesium electrodes on four different paint coatings.
2) Effect of electrolytes containing various mixtures of salt and fresh waters.
3) Effect of magnitude of cathodic current.

All laboratory tests were conducted at room temperature in glass jars, 12 inches in diameter and 12 inches high, with wooden covers. From the center of each cover was suspended a magnesium anode, consisting of a cylindrical rod 1 5/16 inches in diameter and six inches long. Steel test panels were also suspended from the cover in a circle around the anode and five inches from it. Figure 5 shows a picture of a typical test set-up. Each test panel, after being thoroughly cleaned by shot-blasting, was completely coated with paint with the exception of a one-inch square section or window on the surface facing the anode. Six test panels of a given coating were tested in each jar, three being connected to the anode by a copper wire or by a wire and a rheostat where control of current was desired, and three being left uncoupled. The jars were filled with electrolyte to within ½ and ¼ inch of the tops of the panels and the anode, respectively.

Results of Laboratory Tests

The tests on four different paint coatings, using a magnesium anode and a straight sea water electrolyte with no control of the cathodic current, gave widely divergent results. Table I describes these paint coatings and the method of application on the test panels. The fourth coating, a synthetic resin, was applied to the test panels by the manufacturer and the exact method of application and number of coats involved is not known. Because it is a baked-on coat-

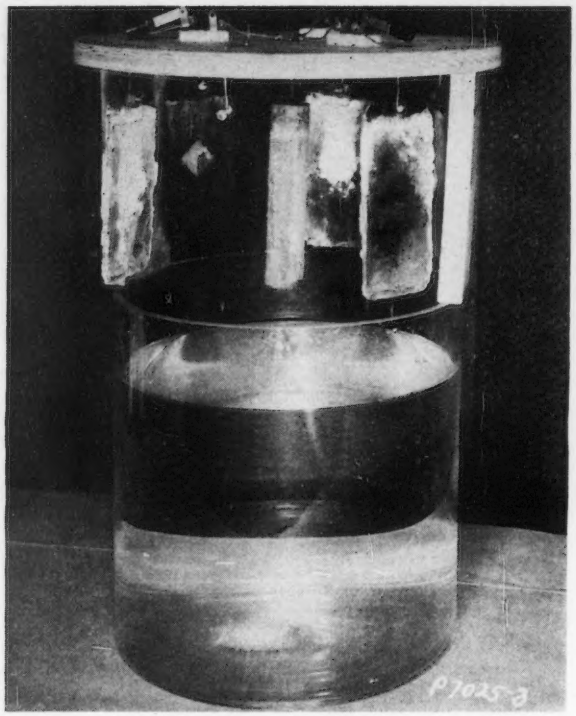

Figure 5—Cathodic protection test set-up.

ing and therefore is impractical for application to transformers, no effort has been made to obtain the missing information. It was included in the test for comparative purposes only.

In all four types of paint coatings, the paint on the uncoupled or control panels showed no peeling or blistering but there was some rusting at the unpainted windows. On the panels connected to the magnesium anodes, the unpainted windows became completely coated with a heavy white deposit, primarily magnesium hydroxide, within 14 days. This deposited coating protected the metal underneath from further corrosion throughout the test.

Table II shows the chemical composition of two samples of this deposit, one taken from the window of an asphalt base test panel and one from the bottom of the test jar containing this panel.

Peeling of the paint on the panels connected to the anodes was first noted after 1, 3 and 11 days on the asphalt base, phenolic resin and baked-on synthetic resin coatings, respectively. In all cases, this peeling first occurred around the unpainted windows.

The coatings were entirely peeled from the fronts of the panels in 15 and 21 days for the asphalt base and the phenolic resin paints, respectively. The baked-on synthetic resin coating offered more resistance and, after 119 days of test, 35 percent of the coating still adhered to the front of the panel.

Unlike the other coatings, the vinyl coating showed no peeling but small blisters formed around the unpainted windows in from 18 to 23 days, and gradually increased in number and in size until 20 to 25 percent of the coating on the front of each panel was covered with blisters after 92 days of test. The

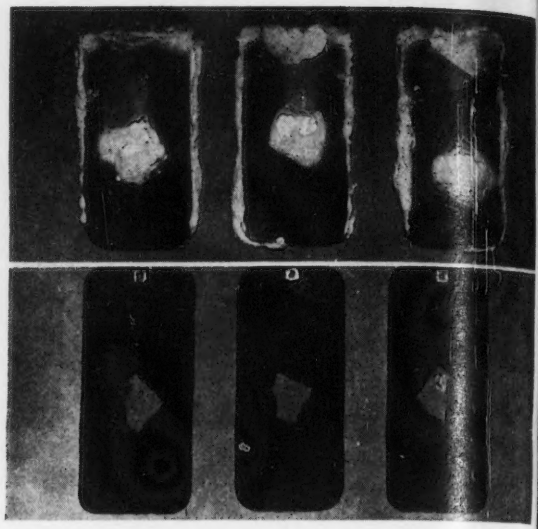

Figure 6—Appearance of test panels after cathodic protection test. Top row—asphalt base paint in sea water, 15 days connected to magnesium anode. Current per panel 49-68 milliamperes. Bottom row—control panels.

test was stopped at this time because of complete disintegration of the magnesium electrode.

Figure 6 shows the appearance of the asphalt base paint test panels after 15 days of test. The heavy white magnesium hydroxide deposits and the complete breakdown of the coatings are plainly visible on the panels that had been connected to the anode. The rust spots on the unpainted windows of the control panels are shown by the dark areas.

Figures 7 and 8 show similar views of the phenolic resin and the vinyl test panels after 35 and 92 days of test, respectively.

Table III is a tabulation of periodic current and voltage measurements made throughout the test. On this test the currents were not controlled and the variations shown are attributed to changes in the area of exposed metal on the panels as the paint

TABLE I

Description of Coatings Tested

Type of Paint	Method of Application	No. of Coats		Drying Time, Hours	
		Priming	Other	Priming Coats	Other Coats
Asphalt	Dipping	0	3	0	24
Phenolic Resin	Brushing	1	2	22	24
Vinyl	Brushing	1	2	1	22
Synthetic Resin	.....	Baked-on		Other details unknown	

All panels dried in room air for 25 days prior to start of test.

TABLE II

Analyses of Deposits in Test Jar and on Window of Asphalt Base Paint Test Panel

		Percent by Weight	
		Test Jar Deposit	Deposit from Window on Test Panel
Magnesium Hydroxide	$Mg(OH)_2$	79.1	86.5
Magnesium Carbonate	$MgCO_3$	6.5	3.8
Magnesium Oxide	MgO	....	6.2
Calcium Carbonate	$CaCO_3$	0.9	.....
Silica	SiO_2	0.3	0.3
Iron Oxide	Fe_2O_3	0.6	1.6
Sodium Chloride	$NaCl$	7.9	1.5
Moisture		4.7	.....

Solution—Salt Water, Anode—Magnesium, Cathode—Mild Steel.

peeled and to the decrease in size of the anode as the test progressed.

The solution, or electrolyte, used in these tests was sea water with an initial pH value of 6.7 and a value of 7.3 after 15 days of test. The resistivity of the solution was less than 50 ohm-centimeters.

In order to investigate the effect of electrolytes consisting of mixtures of tap and sea waters, a similar series of tests were made on asphalt base paint test specimens in straight sea water, in a mixture of equal parts of tap and sea waters, and in a mixture of one part of sea water and three parts of tap water.

TABLE III

Galvanic Current and Potential Measurements

Paint Designation	Initial	After 1 Day	After 7 Days	After 14 Days	After 33 Days	After 77 Days	After 92 Days	After 119 Days
CURRENT IN MILLIAMPERES								
Asphalt	63	49	68	63	..	..	..	..
Phenolic Resin	60	47	29	29	..	..	..	..
Vinyl	83	46	41	38	32	22	1	..
Synthetic Resin	32	33	32	32	41	66	78	78
POTENTIAL IN VOLTS—ANODE TO CONTROL PANEL								
Asphalt	0.97	0.78	0.70	0.69	..	..	..	..
Phenolic Resin	0.99	0.81	0.78	0.76	0.70	..	..	..
Vinyl	0.90	0.79	0.75	0.74	0.76	0.70	0.38	..
Synthetic Resin	0.98	0.77	0.78	0.78	0.78	0.75	0.71	0.64

Solution—Salt Water. Anode—Magnesium. Cathode—Mild Steel.

TABLE IV

Analyses of Deposits in Jars Containing Various Solutions

Solution ...	PERCENT BY WEIGHT		
	100% Sea Water	50% Sea 50% Tap Water	25% Sea 75% Tap Water
Magnesium Hydroxide.....$Mg(OH)_2$.....	79.1	80.2	75.4
Magnesium Carbonate.....$MgCO_3$.....	6.5	7.5	9.4
Calcium Carbonate.....$CaCO_3$.....	0.9	.....	0.9
Silica.....SiO_2.....	0.3	0.2	0.1
Iron Oxide.....Fe_2O_3.....	0.6	2.7	3.3
Sodium Chloride.....NaCl.....	7.9	4.8	3.0
Moisture.....	4.7	4.6	7.9

Anode—Magnesium. Cathode—Mild Steel.

TABLE V

Galvanic Current and Voltage Measurements During Tests on Asphalt Base Paint with Various Test Solutions

Solution	Initial	After 1 Day	After 3 Days	After 7 Days	After 14 Days	Solution Resistivity Ohm-cms	
						Initial	After 15 Days
CURRENT IN MILLIAMPERES							
100% Sea Water	63	49	67	68	63	<50	<50
50% Sea Water, 50% Tap Water	28	30	38	39	40	59	59.5
25% Sea Water, 75% Tap Water	21	17	18	21	23	107	109
POTENTIAL IN VOLTS ANODE TO CONTROL PANEL							
						Solution pH Value	
						Initial	After 15 Days
100% Sea Water	0.97	0.76	0.73	0.70	0.69	6.6	7.1
50% Sea Water, 50% Tap Water	1.02	0.72	0.68	0.68	0.66	7.0	7.1
25% Sea Water, 75% Tap Water	1.00	0.70	0.68	0.66	0.65	7.2	7.1

Anode—Magnesium. Cathode—Mild Steel.

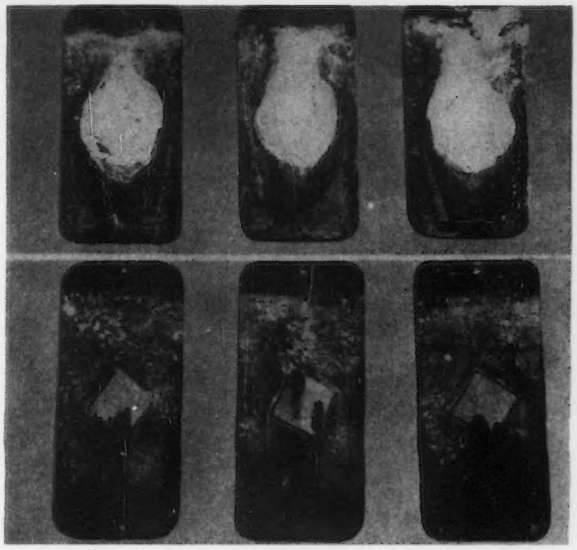

Figure 7—Appearance of test panels after cathodic protection test. Top row—phenolic resin in sea water, 35 days connected to magnesium anode. Current per panel 39-49 milliamperes. Bottom row—control panels.

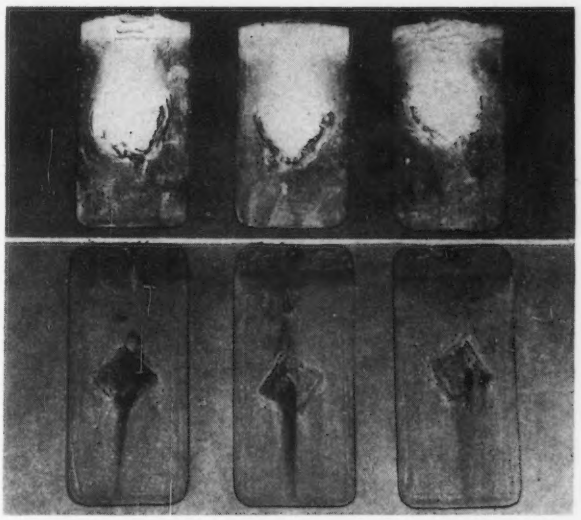

Figure 8—Appearance of test panels after cathodic protection test. Top row—vinyl paint in sea water, 92 days connected to magnesium anode. Current per panel 22-46 milliamperes. Bottom row—control panels.

No difference was noted in the effect on the paint coatings on all panels connected to the anodes. Peeling of the coating started within 24 hours on each panel, and complete peeling of the coating from the fronts of the panels occurred in 15 days.

Table IV shows the chemical composition of the deposits in the bottom of the jars containing the three different solutions. It is to be noted that the amount of iron oxide on these deposits is inversely proportional to the amount of sea water in the solution.

Table V is a tabulation of periodic current and voltage measurements together with the resistivity and pH values of the solutions.

The last series of tests were made to investigate the effect of the magnitude of the cathodic current

TABLE VI
Results of Controlled Galvanic Current Tests on Asphalt Base Paint Coating

	Testing	Time	Days
Electrode Current, Milliamperes	17–68	1.0	0.5
TEST PANELS			
Initial Peeling or Blistering of Paint	1	4	4
50% of Paint Coating, Blistered or Peeled	2	85	140
90% of Paint Coating, Blistered or Peeled	2	140	....
Initial Rusting of Unpainted Window	....	26	26
Initial Magnesium Deposit on Window	2	4	4
Complete Magnesium Coating on Window	14	....	....
CONTROL PANELS			
Initial Peeling or Blistering of Paint	....	85	85
Initial Rusting of Unpainted Window	1	1	1

Solution—Sea Water, Anode—Magnesium, Cathode—Mild Steel.

on the deterioration of the paint coating. For comparison with the original tests at 17 to 68 milliamperes, similar tests were made on asphalt base paint coatings in straight sea water at controlled currents of 1.0 and 0.5 milliampere. There was one significant difference in these tests, however, which must be considered in evaluating the results. The test panels, subjected to the 1.0 and 0.5 milliampere tests, were lifted from the solution and hung in room air for a period of four hours each working day, whereas the test panels, subjected to the higher currents, were kept constantly immersed in sea water.

Results of Controlling Currents

Table VI shows the results of this investigation. At the lower currents, deterioration of the paint coating around the windows of the coupled panels started within four days as compared with one day on the 17 to 68 milliampere test. The rate of subsequent deterioration of the coatings was roughly proportional to the current. Rusting was noted on the unpainted windows of the coupled panels in 26 days on both the 1.0 and the 0.5 milliampere tests, while no such rusting was encountered at the higher currents. This rusting may be attributed to either or all of three factors. First, the complete magnesium hydroxide coating which formed on the exposed metal on the higher current tests was not obtained at the lower currents. Second, the test panels on the lower current tests were subjected to alternate immersion in sea water and in air while those on the higher current tests were subjected to sea water immersion only. Third, the lower current tests were carried on for 140 days, while the higher current tests were stopped after 15 days owing to the complete disintegration of the paint coatings.

Although the indications to date are that cathodic currents of sufficient magnitude to prevent corrosion at breaks in paint coating surfaces cause deterioration of the coatings, it is planned to investigate the effect of other electrode materials and the corrosion-preventing properties of the magnesium hydroxide coating, as deposited from a magnesium electrode, under conditions of alternate immersion in salt water.

It should be emphasized that this is a report of results obtained on an investigation that still is being continued, and was presented to stimulate discussion that can be used as a basis for further investigation of the subject by those interested.

Helpful criticisms and comments during the preparation of this report from several co-workers, particularly Mssrs. A. F. Menzel and L. J. Gorman, are acknowledged.

DISCUSSIONS ARE INVITED

Readers who wish to submit written information additive to articles published in CORROSION, or who wish to register differences of opinion with respect to any articles are urged to send such discussions to Dr. F. N. Alquist, Chairman, NACE Editorial Review Committee, Organic Research Laboratories, 20A Building, Dow Chemical Co., Midland, Mich. Doctor Alquist will submit such discussions to a member of the review committee, and after review and approval the discussion will be published.

The expression of opinions about or the addition of information to that contained in technical articles will advance the interests of NACE and make CORROSION more valuable to the membership.

Discussions

Discussion on **"The Influence of Stress on Corrosion,"** by Julius J. Harwood. *Corrosion*, **6**, No. 8, 249-59 and No. 9, 290-307 (1950) Aug. and Sept.

Comment by John W. Ryznar, National Aluminate Corp., Chicago, Ill.

Mr. Harwood has pointed out a number of factors which tend to substantiate an electrochemical mechanism of stress corrosion cracking.

I would like to bring out one additional factor and that is that at least one type of stress corrosion cracking can be controlled by use of suitable chemical inhibitors.

This is the type commonly known as caustic embrittlement or intercrystalline cracking of steel. The essential conditions for this type of cracking is the presence of a high concentration of caustic soda with some silica in contact with steel under high tensile stress. These conditions are often encountered in steam generating boilers. This type of cracking can be readily prevented by use of sufficient amounts of chemical inhibitors such as sodium nitrate, tannins, and organic compounds such as lignin sulfonates and other lignin derivatives. For sodium nitrate ratios varying from 0.3 to 0.6 nitrate to caustic alkalinity present in boilers are generally required.

When combinations of sodium nitrate with organics such as the lignin derivatives are used in ratios from 1 part of organic to 1 to 2 parts of sodium nitrate the necessary total amount of inhibitor required can be decreased to one-tenth the nitrate required and about one twenty-fifth the organic content required when these are used alone.

The problem of caustic cracking which was at one time quite serious is today no longer considered as such. Chemical inhibitors have it definitely under control.

Questions by J. M. Blalosky, Carnegie-Illinois Steel, Pittsburgh, Pa.:

1. Where the stresses were shown to be considerably lower than the yield stress of the material, were these only the applied stresses or the total applied stresses and internal stresses?
2. Have inhibitors been successfully used for the prevention of stress corrosion?

Comment by H. H. Uhlig, Massachusetts Institute of Technology, Cambridge, Mass.:

One item perhaps deserves mention relative to media affecting stress corrosion cracking of 18-8 stainless steel. This in no way detracts from an excellent summary of an interesting subject. Sodium chloride plus hydrogen peroxide is listed as an environment capable of causing stress corrosion cracking of stressed 18-8. However, the 18-8 specimens recorded as failing in this solution, and I believe Mr. R. H. Brown will confirm this, was previously sensitized by heating in the carbide precipitation range. Hence, in the sense that this specimen would have failed intergranularly in any case, whether or not stress was present, it is not in the same class of media as, for example, magnesium chloride which produces transgranular failure of 18-8 stainless steel, only if the alloy is stressed the critical amount as above. In experiments conducted at the Corrosion Laboratory of MIT, it has never been possible in $NaCl + H_2O_2$ to stress corrosion crack stainless steel of 18-8 composition, properly quenched as is done usually, from about 1050° C.

Author's Reply:

The comments of Mr. Ryznar and Dr. Uhlig are much appreciated. The remarks of the former reply, in part, to the second question asked by Dr. Bialosky. Some evidence also exists that sulfides may be useful in inhibiting the stress corrosion of brass in ammoniacal atmospheres. Other than that I have no information concerning the use of inhibitors for preventing stress corrosion.

With regards to Dr. Bialosky's first question the stresses referred to were those induced by applied loads. In general, for most metals, stresses in the order of the yield strength are necessary to promote stress corrosion, but experiments have been reported, indicating that specimens apparently stressed within the elastic limit were susceptible to attack.

Tabular Cross-Index to Corrosion Technical Material 1945-49

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- ☐ Proceedings, First Annual Meeting, NACE
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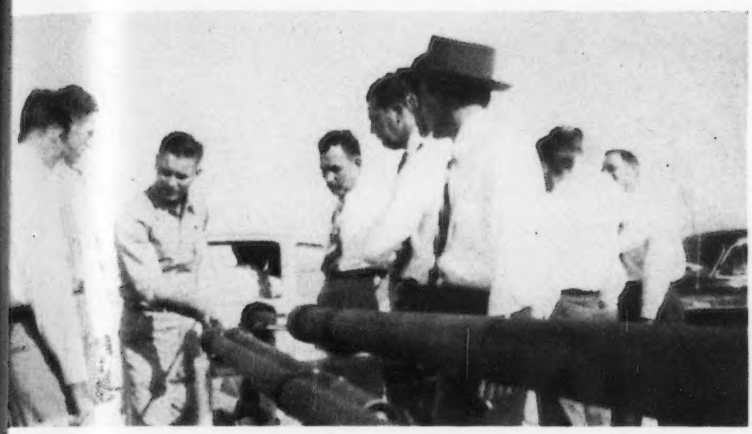
NACE News

261 Register at South Central Region Meeting



Several corrosion engineers are shown using the Tuboscope to inspect the interior of drill stem for evidence of corrosion and pitting during the tour of local industries at the South Central Regional meeting in Houston October 10.

"The work of the corrosion engineer has advanced the knowledge of the workings of corrosion," R. B. McLaughlin, president of the Texas Pipe Line Company, Houston, told members of South Central Region NACE at a luncheon and general business meeting at the Rice Hotel October 9. The two-day annual conference of the region was held at the hotel with a registration of 261. The meeting was featured by extensive presentations of data and informative discussions about corrosion in petroleum transportation, production and refining.

Pipe Line Sessions

Pipe line corrosion sessions were held Monday morning and afternoon, October 9. A symposium on galvanic corrosion in oil wells also was held Monday morning and a general production session Monday afternoon. Tuesday morning was devoted to a session on the economics of corrosion while Tuesday afternoon saw the engineers visit four installations where pipe line work was shown.

Monday night there was a fellowship hour and banquet at San Jacinto Inn, which is at San Jacinto Battleground.

A barbecue supper Tuesday evening was given at Mayes Bros. yards through courtesy of the firm.

Meet in Corpus Christi

The 1951 regional meeting will be held at Corpus Christi, it was determined at the general business meeting. The time and place of the meeting will be set later.

New Western New York Section Organizes, Names Officers and Appoints Committees

Officers were elected and a number of committees appointed at an organization meeting of Western New York Section at Hotel Statler, Buffalo, N. Y. September 15. Officers elected were: G. L. Cox, The International Nickel Co., Inc., 45 Exchange St., Rochester, N. Y., chairman; W. O. Binder, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y., vice-chairman; Dr. J. C. Searer, Durez Plastics and Chemicals, Inc., North Tonawanda, N. Y., secretary-treasurer.

Committees were named as follows by Chairman Cox: Canadian Liaison Committee, T. R. Watson, Dominion Magnesium, Ltd., Toronto, Canada; Membership and Fellowship Committee, E. F. Dunn, Whitehead Metal Products Co., 254 Court St., Buffalo, N. Y.; Program committee, the vice-chairman, Mr. Binder, assisted by: Program, J. E. Shields, Alox Corp., Niagara Falls, N. Y.; Arrangements, M. G. Christie, Socony-Vacuum Co., 503 Elk St., Buffalo, N. Y.; Publicity, Paul R. Guenther, Nukem Products, Buffalo, N. Y.

Rules and Regulations Committee, J. F. Thornberg, Hooker Electrochemical Co., Niagara Falls, N. Y. Conference Coordinating Sub-Committee Member, J. E. Shields.

Chairman Cox was named the Regional Trustee.

Messrs. Hugh L. Hamilton, regional vice-chairman and E. Rowland English, regional secretary-treasurer described plans for a joint meeting between the North East Region and the Western New York section at Buffalo on November 15. Plans were made by officers for this meeting.

A draft of rules and regulations applying to Western New York Section was submitted and given to the rules and regulations committee for study prior to adoption.

NACE CALENDAR

November

15—Joint Northeast Region-West New York Section meeting at Buffalo.
21—Cleveland Section. Symposium on Materials of Construction. Hotel Carter, Cleveland.
21—Chicago Section. "Demonstration of Causes and Control of Electrolysis," by L. E. Plym and M. B. Hart.
22—Corpus Christi Section.

December

6—North East Region trustees, place unannounced.
6—Metropolitan New York Section, Building Trades Employers' Association.
12—Chicago Section. "Meet the President Night," Vance N. Jenkins, guest speaker.
13—Philadelphia Section. Poor Richard Club.
20—Los Angeles Section.

South Central Region Officers Are Elected

Officers elected by the South Central Region NACE at the annual business meeting October 9 at the Rice Hotel, Houston, during the 1950 regional conference were as follows:

George A. Mills, Central Power and Light Co., Corpus Christi, Texas, chairman; M. C. Fleming, Phillips Petroleum Co., Bartlesville, Okla., vice-chairman; Harry E. Waldrip, Gulf Oil Corp., Houston, Texas, secretary-treasurer; John G. Campbell, P. O. Box 1913, Corpus Christi, Texas, assistant secretary-treasurer.

Sandel Resigns

Resignation of W. J. Sandell as vice-chairman of North Central Region has been accepted with regret by F. L. Whitnew, Jr., NACE director representing the region.

Pittsburgh Section Hears J. J. Jacob, Jr.

"What Management Expects from the Corrosion Engineer," an address by J. J. Jacob, Jr., vice-president of Peoples Natural Gas Company, was featured at the October 19 meeting of Pittsburgh Section NACE. The session was held on the day following the three-day meeting of the Eleventh Annual Water Conference sponsored by the Engineer's Society of Western Pennsylvania at Hotel William Penn, Pittsburgh, Pa. Notices of the NACE session were sent to persons attending the water conference in the expectation many would take the opportunity to stay over for the address by Mr. Jacob.

MEMBERSHIP CARDS AVAILABLE

Association members in good standing will be issued on request a membership card in the National Association of Corrosion Engineers. Address requests to A. B. Campbell, Executive Secretary, 919 Milam Building, Houston 2, Texas.

Corrosion Course

"Introduction to Corrosion," an engineering Extension course of the University of California, Los Angeles, is being taught by Gordon N. Scott, consulting engineer, according to an announcement issued in September. The course, scheduled to meet two and one-half hours weekly for 18 weeks, began Sept. 11.

Jones Is Named to Nominating Committee

D. T. Jones, Western Region Chairman, was unanimously named representative of Western Region on the nominating committee for national NACE officers at a meeting of region trustees September 11 at Southern California Gas Company Building, Los Angeles. Attending besides Mr. Jones were L. C. Dietze, director; L. L. Whiteneck, vice chairman; H. J. Keeling, junior past chairman, and W. M. Schilling, secretary-treasurer.

A nominating committee will be named by the chairman to propose regional officers for the coming year. A letter ballot will be sent members.

•

Advance notices of meetings of organizations other than NACE engaged in corrosion work will be published on request in the "Meetings" column.

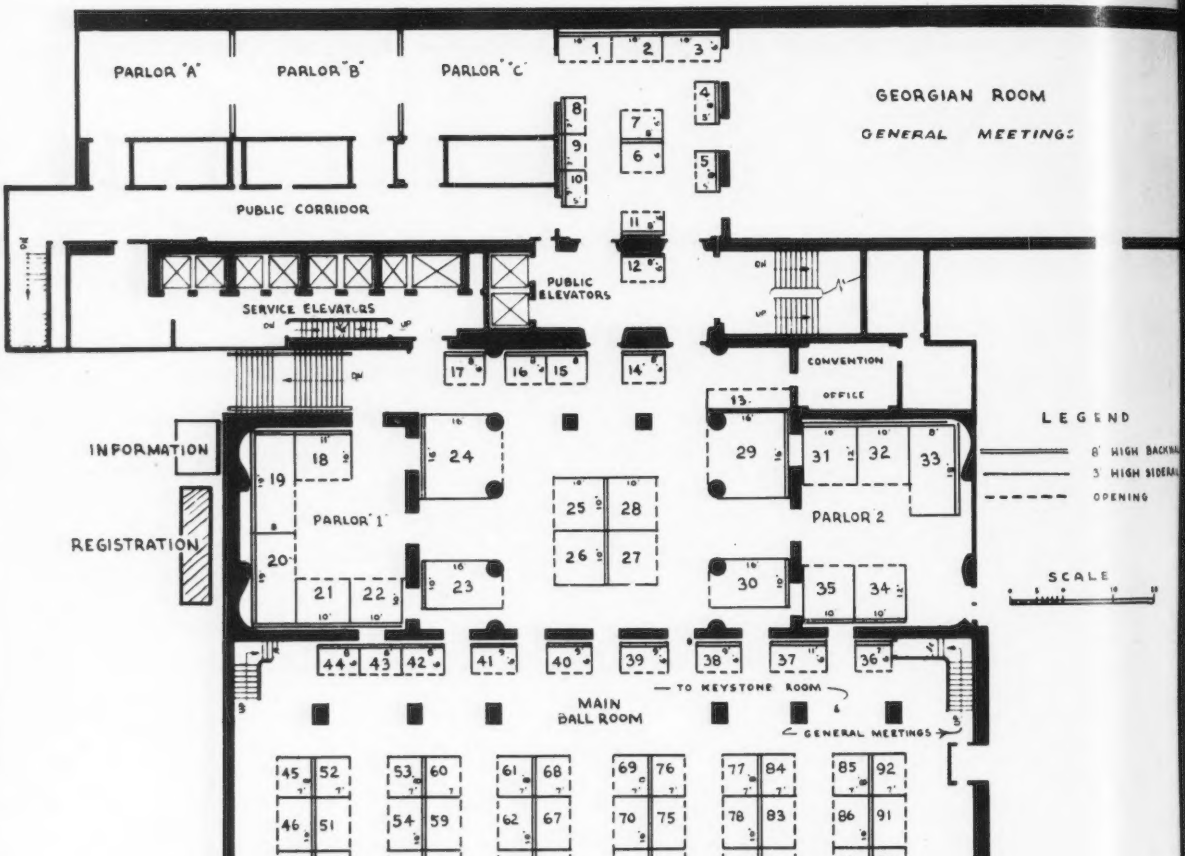


EXHIBIT AREA FLOOR PLAN—The floor plan above is of the exhibit area on the Ballroom Floor of the Statler Hotel, New York City, where the 1951 Exhibit of the National Association of Corrosion Engineers will be held March 13-16 inclusive. Confirming early reports of interest in exhibit space, A. B. Campbell, executive secretary of NACE at Houston, advised early in October that signed space contracts from many companies wishing to exhibit have been received. Exhibit space shown indicates the ideal convention facilities offered by the Statler, assuring exhibitors maximum interest in their displays.

Control House at North Span of 5-mile-long bridge over Lake Pontchartrain, La. Nearly 3,000 ft. of 1 in. and 2 in. Everdur Conduit replaced rusted conduit.

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Corrosion Problems on Underground Telephone Cables Is Discussed at Los Angeles Meeting

Forty-two members and guests of Los Angeles Section attending a dinner meeting June 21 heard D. T. Jones of Pacific Telephone and Telegraph Company talk on "Corrosion Problems on Underground Telephone Cables," a summary of which follows:

Mr. Jones stated that the aim of his company was to render service with a minimum of interruption and a maximum of safety. To replace unsightly overhead wires it developed a cable with up to 200 pairs of wires. This is covered with lead sheath and buried underground. There are 10,000 miles of this in service, of which 3,700 miles are in Southern California.

This cable is subject to mechanical damage caused by ditch diggers, etc., and by electrochemical processes. The causes of corrosion of underground lead are three:

1. Electrolysis, which is 95 percent of the problem. Potentials may easily be measured to a lead sump stick. If the cable is positive to the earth, corrosion is possible; a potential of 0.1 volt or greater being considered a bad condition.
2. Mixed soils. In one instance severe corrosion had occurred where a highway had been realigned and filled with soil from a mountainside. In alkaline soils, cables become anodic.
3. Differential aeration. One case was cited where failures occurred at the point where cables came in or out of a high water table. The submerged cable was anodic to that in drier soil.

Breakdown Is Guide

In this area, complete breakdown has occurred in 18 to 20 months due to electrolysis. Due to the fact that not all electric substations operate continuously, the situation changes hourly, with more current entering the ground at peak periods. Seventy-four pounds of lead sheath are lost in 1 ampere year. In order to combat this loss, it is well to make sure that all rail joints are properly bonded. Any stray current picked up may cause damage because the conductivity of the cable is not always sufficient to carry the current, which leaves the cable and enters the earth. Bonds should be installed of sufficient size to handle all stray currents and return them to the sub-station.

Where stray currents are not great, cathodic protection is used to over-ride them. The cathodic protection stations are mostly owned by the telephone company, but a few are jointly owned with other utilities. All utilities and other operating companies in this area work in cooperation with each other. It is planned to place all toll cables under cathodic protection, as well as all other cables in bad soil areas. Cathodic protection has proven to be highly satisfactory as well as cheap on those toll cables at present under protection.

Galvanic corrosion is not much of a problem in this area because coke is not present. However, in the Compton area several cables were lost because of serious soil corrosion. It was determined that if the cables can be maintained from 0.1 to 0.75 volt negative to earth, corrosion will be stopped. Another source of galvanic corrosion, which has been eliminated, was the former use of iron pipe as a duct for the lead sheath. As the iron oxidized, it became cathodic to the lead, with resulting attack of the lead. Vitrified clay duct has been used

(Continued on Page 6)

"Application Designed" means . . .

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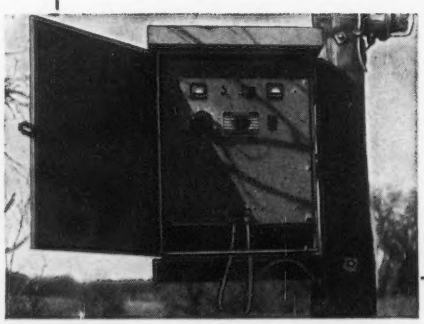

Write Dept. C for New J A-3 Bulletin

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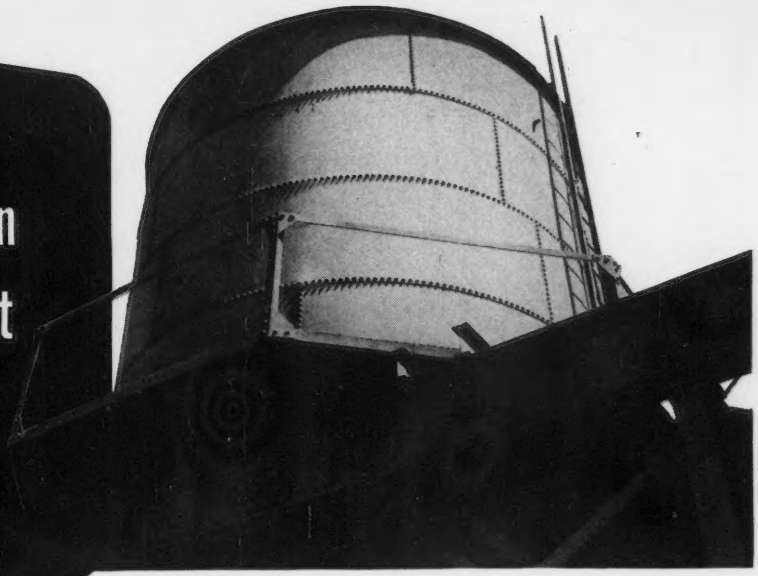

15,000 gallon sprinkler tank. Interior metallized with .006" pure zinc, in 1934—no trace of corrosion in 1950.

The long-lasting, corrosion resistant qualities of pure metallized zinc and aluminum coatings are well known. Life expectancies for protective coatings of this nature, properly applied, usually range upwards of 20-30 years without further attention.

A new series of 18 basic engineering specifications, called the Metco Systems, recently announced by Metallizing Engineering Co., provide the answer to standardization of surface preparation, coating thickness required for various service conditions, and after-coatings of different materials to meet specific requirements.

The result of over 19 years' continuous testing of pure metallized zinc and aluminum coatings in corrosion protection service, Metco Systems cover the protection of structures and equipment under a wide range of corrosion conditions.

These include actual immersion in salt or fresh water of various pH values; exposure to water ballast, condensate and some mild acid solutions; salt, humid, rural and industrial atmospheres ranging from light to heavy. The Systems also contain provisions for appearance requirements with specific organic coatings, available in a range of colors, all thoroughly tested for compatibility with the metallized zinc or aluminum.

The following organizations are set up to provide positive corrosion protection at lower annual cost in accordance with Metco* System specifications. For further information, or a copy of descriptive bulletin, contact the one nearest you.

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Metalweld, Inc. Fox & Hunting Park Ave. Philadelphia 29, Pa. Tel. Radcliff 5-3471	**Nooter Corporation** 1420 South Second Street St. Louis, Missouri Tel. Main 6000	**Thermaflo Metal Products, Inc.** 50 Dell Avenue New London, Conn. Tel. 2-4300	**Arthur Tickle Engineering Works, Inc.** 21 Delevan Street Brooklyn, N. Y. Tel. Main 5-4200

Conference Technical Program Officials Named by Hackerman

Officers in charge of the technical program for the 1951 NACE Conference and Exhibition to be held at Hotel Statler, New York City on March 13-16 inclusive 1951 have been named as follows by Norman Hackerman, chairman of the technical program committee:

Assisting Dr. Hackerman are the following co-chairmen: R. L. Bullock, Interstate Oil Pipe Line Co., Tulsa, Okla.; G. W. Seagren, Mellon Institute, Pittsburgh, Pa. and Aaron Wachter, Shell Development Co., Emeryville, Cal.

Corrosion Principles Symposium: H. H. Uhlig, chairman; M. I. T., Cambridge, Mass.

Water Industry Symposium: R. R. Ashline, chairman; Dept. of Water and Power, Los Angeles, Cal.; A. Damiano, Hackensack Water Company, Weehawken, N. J. and Thomas M. Riddick, Consulting Engineer, New York, N. Y., co-chairmen.

Pipe Line Industry Symposium: S. S. Smith, chairman; Shell Oil Co., New York, N. Y.; W. E. Huddleston, Huddleston Engineering Co., Bartlesville, Okla., and I. B. Tietze, Phillips Pipe Line Co., Bartlesville, Okla., co-chairmen.

Chemical Industry Symposium: W. Z. Friend, chairman; International Nickel Co., Inc., New York, N. Y.; Mars G. Fontana, Ohio State University, Columbus, Ohio and F. A. Rorhman, University of Colorado, Boulder, Col., co-chairmen.

Transportation Industry Symposium: Merritt A. Williamson, chairman; Pullman-Standard Car Mfg. Co., Hammond, Ind.; Otto E. Kirchner, American Airlines, New York, N. Y. and Joseph Winlock, The Budd Co., Philadelphia, Pa., co-chairmen.

Protective Coatings Symposium: Kenneth Tator, chairman; Kenneth Tator Associates, Coraopolis, Pa.; C. G. Munger, Amercoat Corp., South Gate Cal., and Raymond P. Devoluy, C. A. Woolsey Paint and Color Co., Inc., New York, N. Y., co-chairmen.

Oil and Gas Industry Symposium: T. S. Zajac, chairman; Shell Oil Co., Houston, Texas; H. E. Waldrip, Gulf Oil Corp., Houston and E. Q. Camp, Humble Oil and Refining Co., Baytown, Texas.

Cathodic Protection Symposium: Sidney E. Trouard, chairman; New Orleans Public Service Corp., New Orleans, La.; A. W. Peabody, Ebasco Services, Jackson, Miss. and Y. W. Titterington, Dowell Incorporated, Tulsa, Okla., co-chairmen.

Electrical and Communications Industries Symposium: Kenneth G. Compton, chairman; Bell Telephone Laboratories, Murray Hill, N. J.; Walter G. Honecker, Indiana Bell Telephone Co., Indianapolis, Ind. and H. N. Trueblood, Dobbs Ferry, N. Y., co-chairmen.

Symposium on Industrial Use of Corrosion Inhibitors: Aaron Wachter, chairman; Morris Cohen, National Research Council, Ottawa, Canada; and John W. Ryznar, National Aluminate Corp., Chicago, Ill., co-chairmen.

Round Table on General Corrosion Problems: F. L. LaQue, chairman; The International Nickel Co., Inc., New York City.

Round Table on Pipe Line and Underground Corrosion: R. L. Bullock, chairman.

Los Angeles Section

Los Angeles Section met at Rodger Young Auditorium, Los Angeles, September 20, for the following program after dinner: "Outline of Problems in the Seafood Industry," W. C. Stretton of VanCamp Sea Food Company; a round table discussion of cathodic protection problems and the second of three motion pictures, "Drilling for Oil," supplied by the Shell Oil Company.

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New York Conference News To Be Given

Members of the NACE will be given up-to-date information on progress of plans for the 1951 NACE Conference and Exhibition through the Conference Coordination Committee headed by T. P. May. A member of this committee has been appointed for each region and section, and it is planned to provide advance copies of all press releases, schedules, programs and entertainment features to the local committee representative for distribution to local members.

T. P. May

It is hoped members' suggestions concerning conference details will be passed back for consideration by the General Committee through these same channels.

Corrosion Problems—

(Continued from Page 4)

to a great extent, but soil flows in and plugs it.

Polyethylene Sheaths

Lead was used for sheaths for 50 years, until World War II caused a serious shortage. Bell Laboratories worked for many years on the problem of a substitute material, and after the war the work was accelerated. A polyethylene coating was developed, and has been under test by operating companies for more than 18 months. This coating consists first of a paper tube around each wire. The wires are set up in units with a paper tube over all, extruded aluminum over the paper to act as a water barrier, and polyethylene extruded over the aluminum. This coating is known as Alpeth (Al = aluminum-peth = polyethylene) and is now free of stress failures. A newer cable will have a thin tube of steel between the aluminum and the polyethylene to give rigidity. As the steel and aluminum are in contact all the way, no galvanic cell will be set up. Certain minor objections to polyethylene are its comparatively low melting point, slight solubility in oils, and the fact that it tries to resume its former shape.

Discussion Is Lengthy

During the lengthy discussion which followed, several additional facts were brought out. Power companies use bare copper wire as grounds to equalize potential drops between the manholes. Circulating AC from these grounds cause a pulsating current on the lead sheath, and increase corrosion. Due to the fact that lead is amphoteric, over voltage from cathodic protection may damage it. However, this occurs only in an alkaline environment. Aluminum may have been used in the Alpeth coating because it is nonmagnetic, and it is used as a water barrier, due to the fact that polyethylene will pass water vapor. However, no water itself will be passed, and it is estimated that the polyethylene will last at least 50 years.

Billhartz to Address Houston NACE Group

Harold J. Billhartz, Atlantic Refining Co., Dallas, Texas, chairman of Technical Practices Sub-Committee 1-C on Sweet Oil Well Corrosion, will address Houston Section NACE on the work of his committee at the section's November 14 meeting at Guy Francis' restaurant.

T. E. Willier, Houston Traffic Engineer will speak on Houston's traffic problems as the coffee speaker between the dinner and the technical section of the meeting.

Treseder Will Head TP-1G on Sulfide Stress Corrosion

Technical Practices Sub-Committee 1-G on Sulfide Stress Corrosion will be a permanent sub-committee of TP-1 on Corrosion of Oil and Gas Well Equipment, it was reported by Ted S. Zajac, Shell Oil Corp., Houston, chairman of TP-1. Richard S. Treseder, Shell Development Co., Emeryville, Cal. was named chairman of the new sub-committee.

The action was taken, Mr. Zajac said, after formation of the committee was found necessary by the Steering Sub-Committee of TP-1 because of the seriousness of this problem in areas producing sour crude.

ASTM Elects And Reelects Corrosion Committee Officers

Chairmen and secretaries of American Society for Testing Materials technical committees recently elected and reelected as reported in the September, 1950, ASTM Bulletin include: (Asterisk denotes new officer.)

A-5 on Corrosion of Iron and Steel. T. R. Galloway, Consolidated Edison Co. of New York, Inc., New York 3, N. Y., chairman; H. F. Hormann, Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York 3, N. Y.

B-3 on Corrosion of Non-ferrous Metals and Alloys. K. G. Compton, Bell Telephone Laboratories, Inc., Murray Hill, N. J., chairman; A. W. Tracy, The American Brass Co., Waterbury, Conn., secretary.

C-3 on Chemical Resistant Mortars. *F. O. Anderegg, John B. Pierce Foundation, Raritan, N. J., chairman; *Beaumont Thomas, Stebbins Engineering and Manufacturing Co., Watertown, N. Y., secretary.

D-1 on Paint, Varnish, a Lacquer and Related Products. W. T. Pearce, Bala-Cynwyd, Pa., chairman; C. H. Rose, National Lead Co., Washington 6, D. C., secretary.

•

Notices of meetings to be held by NACE subdivisions will be carried in the "NACE Calendar" if received in time.

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Corrosion News Deadline:
10th of Month *PRECEDING* Date of Issue

Good Papers Still Can Be Used at New York

The technical program committee for the 1951 NACE Conference to be held at Hotel Statler, New York City, March 13-16, 1951 inclusive still has places for good papers in some areas of the schedule, it was announced by Norman Hackerman, chairman of the committee. Persons who know of suitable papers are asked to advise Dr. Hackerman at Texas State University, Austin.

The Food Industry Symposium has been dropped from consideration, Dr. Hackerman advised. No replacement has been announced.

No organized effort will be made to secure or prepare preprint copies of technical papers to be presented at the conference, Dr. Hackerman said.

AIChE Meeting

Forty-two papers covering glass manufacture, viscous materials, phase equilibria, air pollution, ultrasonics and other topics are scheduled to be delivered at Columbus, Ohio, December 3-6 during the 43rd annual meeting of the American Institute of Chemical Engineers.

Requests for advance registrations should be addressed to E. J. Bradbury, Batelle Memorial Institute, 505 King Ave., Columbus, Ohio.

Conference Hospitality Plans Being Made

W. H. (Bill) Aretz states that the Hospitality Committee, of which he is chairman, will do its best to make every member attending the 1951 NACE Conference and Exhibition enjoy his stay in New York City. In this effort he is expecting to have the support of the local members of the Conference Coordinating Committee, who will report on members planning to attend.

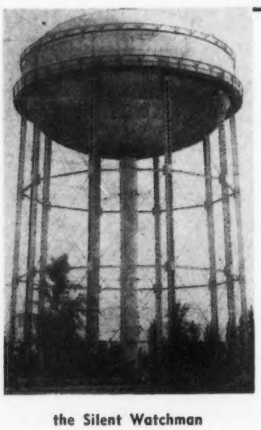
Aretz

Hospitality will be stressed at the "March in New York" conference to make every member—the newest and the oldest—feel welcome to the conference and the city.

Case Registers 201 At September Course

Registration for the Case Institute of Technology's Corrosion Short Course at Cleveland, Ohio, September 25-29 was 201, according to R. B. Hoxeng, Professorial Lecturer at Case and in charge of the course. There were eight lecturers registered in addition. A few applications for attendance had to be turned down because there was insufficient accommodation for them even after the facilities were expanded, Mr. Hoxeng reported.

About 100 memberships in the National Association of Corrosion Engineers were obtained as a result of the course, Mr. Hoxeng said.



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BOOK REVIEWS

DATA ON CORROSION AND HEAT RESISTANT STEELS AND ALLOYS — WROUGHT AND CAST. Sponsored by American Society for Testing Materials Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. 80 pages, 6 x 9, Paper cover. Special Technical Publication No. 52-A. ASTM, 1916 Race St., Philadelphia. Per Copy $2.50

New tables of data on compositions and properties of wrought corrosion-resistant and heat-resistant chromium and chromium nickel steels and alloy castings, assembled by Subcommittee I on Classification of Data of ASTM Committee A-10 on Iron-Chromium-Nickel and Related Alloys. The publication brings up to date a previous compilation on wrought stainless alloys and includes a comprehensive new section devoted to cast alloys.

SYMPOSIUM ON EVALUATION TESTS FOR STAINLESS STEELS. Presented at the 52nd Annual Meeting, American Society for Testing Materials, Atlantic City, June 30, 1949. Special Technical Publication No. 93. 236 pages, 6 x 9, Paper cover. ASTM, 1916 Race St., Philadelphia 3, Pa. Per copy $2.50

A critical appraisal of some testing methods in use for evaluating certain corrosion resistance characteristics of iron-chromium-nickel and related steel alloys. Special attention is focused on the significance of results of laboratory tests related to practical experience and the effect of behavior of alloys in tests and in use of bringing carbon to extremely low limits.

Topics covered include detailed table of solutions to detect sensitization, comparison of results of evaluation tests, table of effects of stress relief and stabilizing anneals, low carbon 18-8, low-carbon austenitic steels, accelerated tests of weldments, appraisal of methods for evaluating corrosion resistance, tests for intergranular susceptibility, influence of carbon and molybdenum on intergranular corrosion, comparative corrosion resistance in various acids, comparison of plant corrosion tests results with Huey and Strauuss tests, plant corrosion tests of welded steels, testing multiple specimens in modified boiling nitric acid test. There are many tables and illustrations.

Names of Elements Set in Netherlands

At the XV Conference of the International Union of Chemistry meeting in Amsterdam, The Netherlands, September 5, the names of eight recently discovered elements were confirmed, conflicting names for three elements were resolved, and the spelling of two others clarified. The following table includes names agreed upon:

Atomic No.	Former Name(s) European-American	Confirmed Name
4	glusinum-beryllium	beryllium
41	niobium (Nb)-columbium (Co)	niobium (Nb)
43	masurium	technetium
61	prometheum	promethium
71	lutecium	lutetium
74	wolfram (W)-tungsten (W)	wolfram (W)
85	alabamine	astatine
87	virginium	francium
91	protoactinium	protactinium
93	no name	neptunium
94	no name	plutonium
95	no name	americium
96	no name	curium

Reference: Chemical and Engineering News, Vol. 27, No. 42, Oct. 17, 1949, pages 2996-2999 +.

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Corrosion mitigation processes and materials are publicized free of charge in CORROSION's "New Products" section. NACE accepts no responsibility for accuracy of performance claims.

Chicago Section

"Demonstration of Causes and Control of Electrolysis," is the scheduled topic for the November 21 meeting of Chicago Section. Messrs. L. E. Plym and M. B. Hart will be speakers. Host will be Graver Tank and Mfg. Co. and chairman C. L. Van Natta.

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Central Office NACE will attempt to ship on request of authors of technical articles published in CORROSION during the years 1945-49, inclusive, printing plates used in publishing their articles in CORROSION: 1) To the extent that cuts still are available in NACE cut files, and 2) After payment of a $5 service charge.

•

NACE accepts no responsibility for cuts missing for any reason. NACE will retain for its own use cuts of individuals.

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This offer will expire as of December 1, 1950, after which date all cuts unclaimed in the years 1945-49 will be destroyed.

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Cuts used in the publication of technical articles in 1950 will be made available on the same basis six months after publication in CORROSION.

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(Changes Through Sept. 29, 1950)

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ILLINOIS

BUNTING, WILLIAM E., Dowell Incorporated, 343 S. Dearborn, Room 1402, Chicago, Ill.

LAWSON, J. M., Chief Engineer, The Globe Oil & Refining Co., Lemont, Ill.

MICHIGAN

COGSHALL, JAMES H., Pennsylvania Salt Mfg. Co., Wyandotee, Mich.

RAYNER, REID L., Michigan Bell Telephone Co., 1365 Cass Ave., Detroit 26, Michigan.

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JORDAN, MELVIN N., Texas Pipe Line Co., Basin System, Box 600, Wichita Falls, Texas.

SELLE, JOSEPH B., The Ohio Steel Foundry Co., 4215 Graustark St., Houston 6, Texas.

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(Old Address Follows New Address in Parentheses)

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TUTHILL, ARTHUR H., Eng. Dept., E. I. duPont Co., Wilmington, Del. (Standard Oil Co. of New Jersey, Louisiana Div., Baton Rouge, La.)

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ZANGE, MAX, BOQ Bldg., Granite City Engineering Depot, Granite City, Ill., c/o Warwick Hotel, St. Louis 3, Mo.)

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LOUISIANA

CRAIG, JAMES H., P. O. Box 10128, New Orleans, La. (3105 Pickwick Lane, Houston, Texas)

HARGRODER, A. D., Mathieson Chemical Corp., Lake Charles, La. (Mathieson Alkali Works, Lake Charles, La.)

MARYLAND

PRUTTON, C. F., Englemeade Rd., Stevenson, Md. (Spotswood, Woodbrook, Baltimore 12, Md.)

MISSOURI

KRUSZYNSKI, EDWARD A., Chemical Enterprises, 1813 North 17th St., St. Louis 6, Mo. (5001 Oleatha, Apt. 3, St. Louis 9, Mo.)

WHITNEY, F. L., JR., Monsanto Chemical Co., 1700 S. Second St., St. Louis, Mo. (Whitney, F. L., Monsanto Chemical Co., 1700 S. Second St., St. Louis, Mo.)

NEW YORK

COOK, GEORGE S., 15 Glen Cove, Scotia, N. Y. (2869 S. Buchanan St., Arlington, Va.)

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PLOEDERL, FRANCIS J., Permolite, Inc., P. O. Box 807, Hamilton, Ohio, (Permolite, Inc., North 5th & Ford Blvd., Hamilton, Ohio)

OKLAHOMA

CASE, L. C., Gulf Oil Corp., Box 661, Tulsa, Okla. (206 Sunset Dr., Tulsa, Okla.)

OREGON

BAUNACH, ROBERT P., JR., 1859 S. W. Park Ave., Apt. 203, Portland, Ore. (New Jersey Bell Telephone Co., 540 Broad St., Newark, N. J.)

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DIECKS, A. NORMAN, 1311 Widener Bldg., Broad & Chestnut Sts., Philadelphia 7, Pa. (Apt. 417, 3128 W. Wisconsin Ave., Milwaukee 8, Wis.)

HESS, ALBERT W., 1401 N. Broad St., Philadelphia 8, Pa. (Reynolds Metals Co., 1600 Arch St., Philadelphia 3, Pa.)

STROMQUIST, RUSSELL C., Prod. Mgr., Koppers Co., Inc., Tar Products Div., Koppers Bldg., Pittsburgh, Pa. (Koppers Co., Inc., Koppers Bldg., Pittsburgh 19, Pa.)

TRACEY, EDWARD J. JR., 1227 Old Boalsburg Rd., State College, Pa. (The Pennsylvania State College University Club, State College, Pa.)

TENNESSEE

BRASUNAS, ANTON DESALES, c/o General Delivery, Oak Ridge, Tenn. (Dept. of Metallurgy, Mass Inst. of Technology, Cambridge 39, Mass.)

TEXAS

BRADLEY, BRYANT W., 3227 Elmridge, Houston 2, Texas (1657 Castle Court, Houston 6, Texas.)

KELLY, WARNER M., Otis Pressure Control, Inc., 2402 Broad St., Houston, Texas. (Otis Pressure Control, Inc., 6705 Navigation, Houston, Texas)

KRELL, ABRAHAM J., 2303 Wroxton Rd., Houston 5, Texas. (6524 Kenwell, Dallas 9, Texas)

OSBORN, OLIVER, 225 Jasmine, Lake Jackson, Texas. (615 West 4th St., Freeport, Texas.)

SNEDAKER, DELBERT G., Electrolysis Engineer, P. O. Box 7119, Houston 8, Texas. (SNEDAKER, DELBERT G., P. O. Box 7119, Houston 8, Texas.)

FOREIGN

HEWITT, HARRY N., Shell Oil Company of Canada, Ltd., Shell Oil Refinery, Montreal East, P.2, Canada. (11985 Poincare St., Montreal 12, Quebec, Canada.)

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PIPE COATING DATA

Communication No. 25, of the Central Institute for Research on Materials, P. O. Box 49, Delft, Holland, Corrosion Department (in English) is a report of the Dutch Corrosion Committee II for the Study of Soil Corrosion and Protection of Pipelines. Subject of the report: Prescriptions for the coating of steel pipes smaller than 75 mm inside diameter with blown asphalt bitumen. The report gives detailed information on the preparation, application, testing specifications and descriptions of test methods. The paper-bound book has 48 pages 5½ x 8 inches.

Clippings on Corrosion

Extracted from Current Periodicals

GLASS FIBER TUBE IS NOW ON MARKET

(From *World-Telegram and Sun*, New York. Aug. 28, 1950)

A tube and pipe material intended as a replacement for steel and other critical metals was announced by the United States Plywood Corp. The material is known as "Glasweld." It is available now as piping in the oil and chemical processing industries and as tubing in building, electrical and allied fields.

•

COMPANY IS FORMED TO MANUFACTURE TITANIUM

(From *New York Times*, Aug. 25, 1950)

Rem-Cru Titanium, Inc., has been formed to manufacture titanium and alloy products. C. K. Davis, president and general manager of Remington Arms Co. Inc. was elected chairman and W. H. Colvin, Jr., of Crucible Steel Co. of America, was elected president. The firm is owned jointly by the two companies and has headquarters in Bridgeport, Conn.

•

EXPLOSIONS ATTRIBUTED TO CORROSION IN KEG

(From *Times-Register*, Bedford, Ohio, Aug. 18, 1950)

Officials at the Aluminum Smelting and Refining Co., 5463 Dunham Rd., Maple Heights said corrosion inside an aluminum keg thrown into an open hearth furnace was the cause of two explosions at the plant. No one was injured and no damage was caused, police investigators reported.

•

FARMERS WARNED ABOUT LIGHTNING ROD CORROSION

(From *Guardian*, Stafford, Ariz. July 21, 1950)

A county agent, pointing to heavy loss in life and property on farms from fires caused by lightning warned farmers to inspect lightning rods for damage from corrosion.

•

CORROSION-PROOFING USED ON ARMY "EAGER BEAVER"

(From Anderson, Ind. Herald, Aug. 26, 1950)

Delco-Remy units used on the army's "Eager Beaver" truck engine are designed to be waterproof, mildew proof and corrosion resistant. The truck can be driven with the engine submerged in water.

CORROSION-PROOF LININGS CEMENTS BRICK

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•
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IF YOU SELL A CORROSION SERVICE
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NEW PRODUCTS – Materials – Service – Literature

"Karbate" impervious graphite globe valves' spindles are highly resistant to corrosion and wear in service involving repeated opening and closing, recent experience has indicated. The self-lubricating threads on the bonnet and spindle of these valves have been in continuous service for over two years, handling sulfuric acid, without material wear. The valves are manufactured by National Carbon Division, Union Carbide & Carbon Corp., New York 17, N. Y.

Corrosion-Resistant Monel wire uses are described in a 4-page folder featuring a sample of Monel wire available from The International Nickel Co., Inc., 67 Wall St., New York City.

•

Aquatrol, Inc., services and four classes of inhibitors for treatment of industrial and boiler water are described in a multi-color, illustrated 12-page folder available on request from Aquatrol, Inc., P. O. Box 12233, Houston, Texas. The four classes of products are designed to inhibit corrosion, control algae, scale and carbonates.

•

"Beauty-Shield," a coating based on Vinylite resins, is being used successfully for spray application on inside and outside surfaces for decorative and weather protection, according to Plastic Coating Corp., P. O. Box 13127, Houston 19, Texas, and Plastic Coating Corp., Suite 1841, 30 Rockefeller Plaza, New York City. The coating is available in flat, semi-lustre and gloss finishes and a wide variety of colors. It is suitable for application to almost all building surfaces, manufacturers and applicators claim.

•

"Carclad" a coating based on Vinylite resins is being applied successfully to railroad hopper cars handling acid, alkalis and other corrosive chemicals, according to Sherwin-Williams Co., Cleveland 1, Ohio. Test cars painted with the material remained corrosion-free after three years' service carrying soda ash, manufacturers say. Weather durability is high, abrasion resistance is unusually good and while aromatic hydrocarbons, ketons, esters and some chlorinated hydrocarbons will soften the finish, it will return to its original state if allowed to dry without abrasion.

•

Product Information about heat exchangers, evaporators, feedwater heaters, pressure vessels and pipe are included in Catalog AL-3, available from Public Relations Department, American Locomotive Co., Schenectady, N. Y. The catalog, among other things, contains 60 cutaway and cross-sectional drawings of equipment.

•

"Water Side Deterioration of Diesel Engine Cylinder Liners," by F. N. Speller and F. L. LaQue is available in reprint form from The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y. The article is reprinted from July Corrosion.

•

Molybdenum-Base lubricants designed to meet high pressure and temperature conditions are being produced in four new types: Liqui-Moly NV Regular and Grease, Liqui-Moly NV Thread Compound and Moly-Wax-Stix. The material, a molybdenum bearing liquid containing no oil is transported to the bearing surfaces where the liquid vehicle evaporates and leaves the molybdenum metallic lubricant on the bearing surfaces. The resulting coating permits operating the dry bearing at double the pressures possible with conventional lubricants and at several hundred degrees higher temperatures, manufacturers say. Technical Bulletin 21 E, available on request from The Lockrey Company, College Point, N. Y. gives further information about these materials.

•

Heat Transfer Equipment manufactured by Henry Vogt Machine Co., Inc., Louisville, Ky. is described in Bulletin HE-5 recently issued. Alloy exchangers for use in corrosive environments are described and illustrated.

ACIPCO PIPE
Resists CORROSION

Mono-Cast Centrifugal Cast Iron Pipe
High resistance to Soil Corrosion

Used extensively for:
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- HIGH ALLOY, including
- 18/8 & 25/20 CHROME-NICKEL

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DEPENDABLE . . EFFICIENT . . LONG LIFE

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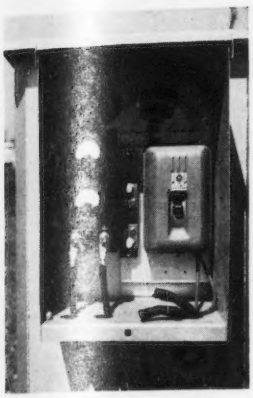
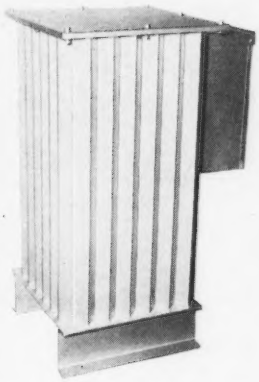
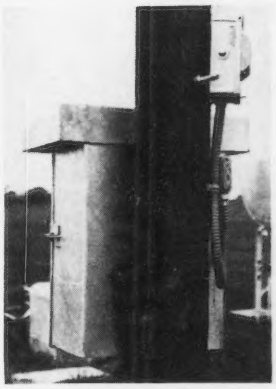


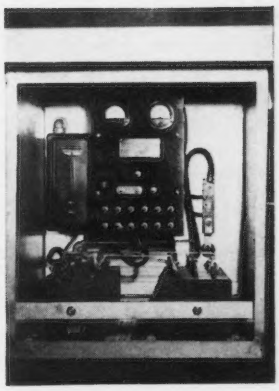
Oil-immersed, selenium rectifier —field installation showing meter and terminal box.



The NEW Westinghouse oil-immersed selenium rectifier—a 24V, 90 amp. unit just 43 inches high overall—36 gallons of oil suffice where 150 gallons were required in identical units of previous design.



Brance-Krachy air-cooled selenium rectifier in location showing pole mounting. (Method of connecting dc and ac leads optional.)



Typical unit construction—Brance-Krachy air cooled, selenium rectifier. Note sturdiness and easy accessibility.

OIL IMMERSED RECTIFIERS

Westinghouse selenium rectifiers have long been recognized for their quality featuring:

★ 11 ga. plate construction, bonderized—completely weather proof.

★ Large meter and terminal box easily accessible for making connections and reading meters.

★ AC circuit breaker equipped with heater type thermal overload relays.

★ Unitized construction of power unit for easy removal and inspection.

AIR-COOLED RECTIFIERS

New design features in Brance-Krachy air-cooled, selenium rectifiers are scaled to meet the demand for compactness and ruggedness in construction in this type of unit. These rectifiers are unsurpassed in quality, yet economical in terms of initial investment and years of trouble free performance. They feature:

★ 11 ga. plate construction—bonderized, or hot-dip galvanized after fabrication — case completely insect proof.

★ Fansteel selenium stacks—normally derated for operation at 60° ambient temperature for extra stack life.

★ AC starter—heater type overload protection.

★ Heavy duty transformer construction with strap type secondary top changer. We will build the unit to meet your requirements.

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ADD VALUABLE YEARS OF LIFE AND SERVICE WITH B-K PACKAGED PROTECTION UNITS

Brance-Krachy complete package-type protection units include either copper oxide or selenium, air-cooled or oil-immersed rectifiers, underground "trench wire," graphite and carbon anodes and coke breeze backfill. Complete cathodic protection installations sent to your job as a unit. ALCOA magnesium anodes and M. C. MILLER'S MULTI-COMBINATION METERS in stock. We have all accessories for installing any type cathodic protection installation.

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NEW PRODUCTS

David E. Long Corp., 220 East 42nd St., New York 17, N. Y. has been formed to make and sell corrosion-abatement materials and systems. Materials offered include DEL protective coatings. Series A heavy duty coatings are recommended to protect metals and masonry from acids, alkalis, alcohol, oil, gasoline, salts and water.

•

Chippaflex VPI, an inhibitor-impregnated corrugated wrapper is being manufactured by Chippewa Paper Products Co., Inc., Chicago. The material contains the Shell Development Company vapor phase inhibitor.

•

Vinylite resin-based films were stripped from deck gear of navy ships "mothballed" 4½ years ago to reveal the equipment ready for use after oiling. The vinyl film was sprayed on a web of pressure tape and a vinylite webbing material. Moisture-absorbing silica gel bags were sealed inside the cocoon to absorb excess vapor and inspection windows of clear plastic were provided through which humidity and temperature recording instruments could be read. The gear was ready for service in less than 30 minutes, Bakelite Division of Union Carbide and Carbon Corporation reported.

•

Westcoat-Clear No. 202, a cellulose acetate butyrate, conforms to specifications AN-C-117b, Type II and JAN-C-149, Type II, Western Coating Company, 85 West Union Street, Pasadena 1, Cal. reports.

Spang-Chalfant couplings are galvanized on the outside by the hot-dip process and on the inside by the electroplating process. On 12-inch and up sizes the thread area of the coupling is covered with zinc, important in galvanized piping installations. A nitric acid bath makes the couplings brighter and fingerprint-proof, National Supply Company says.

•

"Corrosion of Brass Pipe and Copper Tubing," a bulletin prepared by Water Service Laboratories, Inc., 423 West 126th St., New York 27, N. Y. is available on request.

•

A Series of Acrylic Polymers, modified sodium polyacrylates which are water-soluble anionic colloids available as clear straw-colored aqueous solutions are available from the Industrial Chemicals Division of American Cyanamid Co., 30 Rockefeller Plaza, New York 20, N. Y. The materials have interesting thickening, suspending, stabilizing and film forming characteristics.

•

An All-Nickel variable area flow meter designed especially for handling caustic streams is described in Catalog Section 40 available from Fisher & Porter Co., Hatboro, Pa. The flow-sentive float is entirely confined within the liquid stream, with no bearings or seals in the system. Flow rate is picked up by means of a magnetic follower.

•

Koppers Company has been awarded a contract to construct 23 gun-flue type coke ovens at Geneva Steel Company's Ironton plant near Provo, Utah.

•

Anti-Abrasion plastic rubber compounds manufactured by Magic Chemical Co., Brockton 2, Mass. are recommended for repairs on conveyor belts damaged by abrasion or corrosive conditions.

•

Seventeen members of the aluminum industry from eight Western European countries in the United States for the purpose of studying secondary aluminum operations recently concluded a series of meetings with representatives of Apex Smelting Company in Chicago and Cleveland.

•

Formulas LKR-12 and 6, proprietary compounds manufactured by L.K.R. Chemical Products Corp., Detroit, Mich. are reported in tests made by Ralph H. Strong, Chemical Consultant, Terre Haute, Ind., to reduce loss of water through concrete protected by the materials to 1.1 percent of the average 6-day loss through uncoated concrete, 1.9 percent of the average 12-day loss and 12.6 percent of the average 54-day loss. Formula LKR also is recommended as a coating for iron.

PERSONALS

Jeffrey R. Stewart, author of a technical manual prepared for the Department of the Army entitled "Cleaning, Preserving, Sealing and Related Materials," soon to go on sale at the Government Printing Office, has been transferred to the Bureau of Yards and Docks, Department of the Navy, Washington 25, D. C.

IN CORROSION PROTECTION

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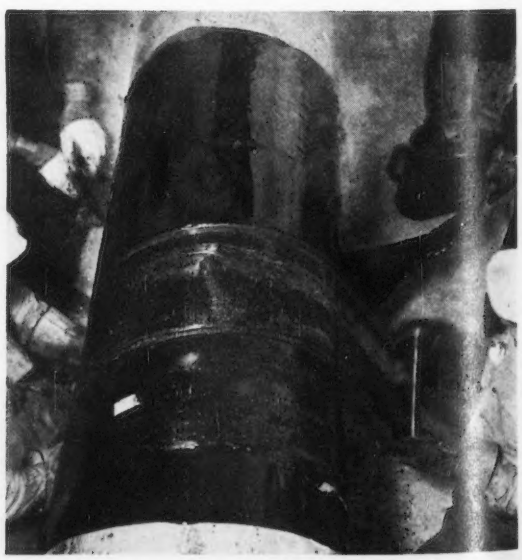
ALWAYS COSTS LESS!

Here Glasfab, the permanent reinforcing cloth woven of glass fibers, protects the joints of an underground pipe line.

The open mesh permits full penetration of the bitumin. Glasfab makes this reinforcing job permanent because it is impervious to moisture and is more than 100% stronger than other reinforcing materials.



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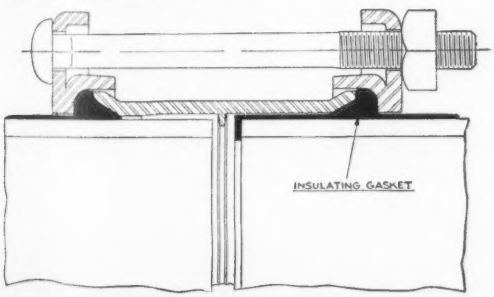
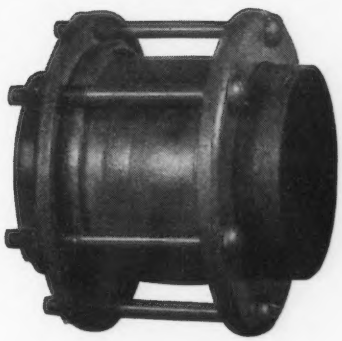
Where it is desirable to sectionalize a main for the application of electrolytic protection—or wherever insulating joints are indicated—Dresser Insulating Couplings, Style 39, provide ultimate protection at lower cost. There is no exact pipe fitting required and the joint itself costs but a fraction of the cost of more cumbersome insulating methods.

An additional advantage is that Style 39's with pipe stop bead removed can be cut into existing mains with a minimum of trouble and expense. Gaskets are of special rubber compound, as shown in cross-section drawing, or with protective plastic skirt where line contents might affect rubber compounds.

Sizes 1½" through 30" and up. Also reducing sizes for going from steel to CIP.





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Dresser ZIPCOATS* complete insulating joint protection... Easy and safe to install

Installed in 1/10 the time it takes to coat a joint, ZIPCOATS give sure protection, superlative dielectric strength. Simply zip them up like a jacket. There's no flame; no heating, hauling or messy application of hot stuff; no danger from fumes or burns. Three types: for insulating joints and for the straight run of pipe, including welds. *Write for literature.*

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20 YEARS is a long time on the job, preventing corrosion damage to underground pipe. SOMASTIC Pipe Coating has furnished complete protection at severely corrosive locations since its first year—1930.

In fact, our knowledge of its useful life is limited only by the total time it has been in existence.

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2 ECONOMICAL METHODS OF APPLICATION:

... by Central Plant

... by portable Railhead Plant

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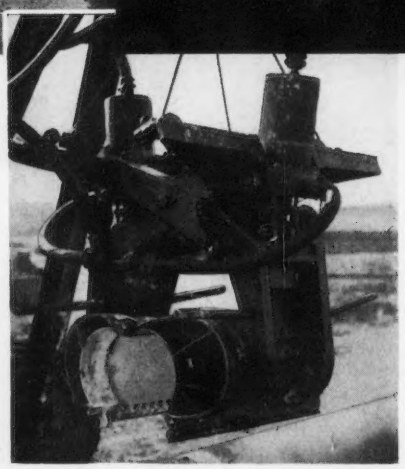
The sure protection of impervious asphalt-mastic—won't distort under soil stresses; resists shock; prevents electrolysis. Ductile; inert; firmly bonded to pipe.

RAILHEAD PLANT. Choice between railhead and central plant depends on the economics of a specific job.



HYDRAULIC FORM. Field joints make SOMASTIC protection continuous along the entire coated line.

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Corrosion Abstracts

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November, 1950

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GENERAL

• Miscellaneous

1.1

Bibliography on the Uses of Punched Cards. Ed. 2. Loma Ferris and others. Punched-Card Committee, American Chemical Society, 40 pages.

218 abstracted references are classified under the following headings: General Descriptions and Techniques; Uses by Scientists; Medical Uses; Library Uses; and Of General Interest. Includes author index.—BLR.

1.1

Causes of Steel Corrosion. I. Richards. *Org. Fin.*, 9, 41-46 (1948) Aug.—BL.

TESTING

• Laboratory Tests

2.3, 2.2, 1.7

Corrosion Testing. Summary of Some Tests Carried Out by the IVA Corrosion Committee. J. Tandberg. *IVA*, 19, No. 5, 227-233 (1948). (In Swedish, with English summary.)

A review of recent Swedish corrosion tests on non-ferrous materials, such as zinc die-castings, aluminum sheet, and on various ferrous alloys. These were tested in solutions of various salts and in moist air. Tests on the moisture permeability of some paints and plastic films are also recorded. Sea-water corrosion tests on commercial aluminum and two alloys containing magnesium show slight differences in favor of the purer material. A marked difference in the influence of Atlantic and Baltic sea water on corrosion is shown in another test. Pure zinc and zinc plated steel included.

2.3, 2.2, 6.3

Corrosion-Erosion Tests on Ni-Resist in Sea Water. *The Nickel Bull.*, **22,** 30-31 (1949) Jan.-Feb.

According to a report published in Nickel Topics, Ni-Resist has for many years past been used successfully to provide resistance to the corrosive and erosive effects of salt water at high velocity, e.g., in such applications as castings and impellers for salt-water pumps. In order to supplement service records, and to provide engineers with quantitative data for comparing high-alloy cast iron with bronze, trials have been carried out in a corrosion-erosion test apparatus at the International Nickel Co.'s Marine Testing Station at Kure Beach, N. C. Specimens used in the tests were in the form of bars measuring about 4 x ¾ x ¼ inch. They were attached, in duplicate pairs, to the periphery of a Bakelite disk which was mounted on a Monel shaft so that it could be rotated at high speed while submerged in sea water in the tank of the machine. The speed of rotation was 380 rpm, providing a calculated speed of 27 ft. per sec. at the tips of the test bars. The action of the testing machine is such as to whip large quantities of air bubbles into the water. The violent agitation of the water by the specimens also served to heat it, so that it was necessary to keep the temperature down by the continuous addition of cooled water pumped directly from the ocean into the testing machine from which it overflowed to waste. By this means, the temperature of the water was held at about 86 deg. F during the test and at the same time the continuous replacement of the water being used for the test provided exhaustion of corrosion products which might have affected the corrosion reactions. The test ran for a total of 1440 hours without interruption for more than a few hours at a time. The extent of corrosion was measured in terms of weight-loss, and the effects produced were also recorded by photographs of the leading edges, which were subject to the most highly concentrated attack. Comparison was made of the behavior of the various grades of Ni-Resist with that of a bronze of the type generally used in applications requiring resistance to the corrosive and erosive effects of sea water. Results confirm the suitability of Ni-Resist cast irons for such applications as sea-water pumps, valve bodies, etc.—TIME.

2.3

Method of Examining Anti-Corrosion Lacquers and Coatings. A. Schall. Board of Trade, Ger. Div., FD. 283/48, Frames 807-840.

Methods of testing physical and chemical properties of coatings are described. Points of test procedure discussed are concentration of lacquers to correct viscosity, testing physical properties and resistance to corrosion, changes in physical properties due to corrosion and electrical testing.—RPI.

2.3, 5.4

Electrical Measurements on Metal Protective Paints. W. E. Shaw and D. L. Hawke, Nat. Lead Co. Res. Labs. *Org.*

PRIMARY SOURCES OF ABSTRACTS PUBLISHED IN CORROSION

AER—Aeronautical Engineering Review, Institute of Aeronautical Sciences, Inc. 2 East 64th St., New York 21, N. Y.

ALL—The Abstract Bulletin, Aluminum Laboratories, Ltd. P. O. Box 84, Kingston, Onatrio, Canada.

AWWA—Journal, American Water Works Association. Amer. Water Works Assoc., 500 5th Ave., New York 18, N. Y.

BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

BLR—Battelle Library Review, Battelle Memorial Institute Library. 505 King Ave., Columbus, Ohio.

BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.

CALCO—Calco Chemical Division, American Cyanamid Corp. Bound Brook, New Jersey.

CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

CEC—Consolidated Edison Co. of New York, Inc. 4 Irving Place, New York 3, New York.

EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.

INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.

IP—Institute of Petroleum. 26 Portland Place, London W#1, England.

MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.

ME—Marine Engineering, The Institute of Marine Engineers. 85/88 The Minories, London E. C. 3, England.

MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.

NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.

NBS—National Bureau of Standards. Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.

PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.

RA—Refrigeration Abstracts, American Society of Refrigeration Engineers. 40 West 40th St., New York 18, N. Y.

RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.

RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London. Waldegrave Rd., Teddington, Middlesex.

TDD—Technical Data Digest, Air Material Command—Technical Service Section, Central Air Documents Office, Wright-Patterson Air Force Base, Dayton, Ohio.

TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.

UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.

ZDA—Zinc Development Association. Lincoln House, Turl Street, Oxford, England.

Fin., **10**, No. 10, 19-22 (1949) Oct.; *Can. Paint & Varnish Mag.*, **23**, No. 6, 18-21 + (1949).

Discussion of the three types of measurements: bulk potential, resistance and capacitance or dielectric constant, as related to metal protective paints on steels, presents some data, describes the experimental set-up for the measurement and offers an explanation of the source of certain of the phenomena being measured. Time potential studies can show when accelerated corrosion commences. Resistance measurements, measured by direct current, are unreliable but resistance measured by alternating current of relative high frequency show at least moisture penetration and may reflect interfacial conditions after moisture penetrations.—INCO.

2.3

Standard Solutions for Humidity Control at 25° C. R. H. Stokes and R. A. Robinson. *Ind. Eng. Chem.*, **41**, No. 9, 2013 (1949) Sept.

Gives relative humidities at 25° C for saturated solutions of 16 salts and for solutions of H_2SO_4, sodium-hydroxide and $CaCl_2$ of various concentrations.—BNF.

2.3, 5.2, 4.3

Porosity of Electrodeposited Metals. V.-Measurement of the Corrodibility of Metal Foils. N. Thon, D. Keleman and L. Yang. *Plating*, **36**, No. 9, 928-929, 959 (1949) Sept.

Reports the change in permeability of three electrolytic foils (sulfate nickel, chloride nickel and sulfate copper) and wrought nickel foil on exposure for up to 125 hours to moist SO_2 and 5% sodium chloride solution. The tests are continuing; this is part of American Electroplaters' Society Research Project No. 6.—BNF.

2.3, 1.8

Measurement of the Rate of Oxidation and Oxide Film Thickness on Metal Surfaces, Also the Local Galvanic Activity Between the Metal and Its Oxide. (In German.) F. Tödt, R. Freier, and W. Schwarz. *Zeitschrift fur Elektrochemie und Angewandte Physikalische Chemie*, **53**, 132-42 (1949) May.

The effects of oxide films on the atmospheric corrosion of metal surfaces (iron, copper, chromium-nickel steel, platinum, and silver) were studied. Rate of oxidation and film thickness were determined by measuring the current density in coulombs per sq. cm. at the metal surface. Data are graphed and tabulated. 17 ref.—BLR.

2.3, 1.8

The Electrochemical Behavior and Rate of Formation of Oxide Films on Metallic, Especially Iron, Surfaces. F. Tödt. (In German.) *Metalloberflasche, Ausgabe A*, **3**, No. 9, 170-173 (1949) Sept.

Electrochemical and chemical determination of thickness of oxide layers; curves for rate of growth of iron oxide at room temperature with increased air supply, and at 350° C, and of a silver iodide layer at room temperature; measurement of action of local elements between oxide layer and free metallic iron. —BNF.

2.3, 1.8

Recent Experiments on the Local Galvanic Action of Oxide Coatings on Metal Surfaces. (In German.) F. Tödt. *Archiv fur Metallkunde*, **3**, 273-278 (1949) Aug.

Above was studied by amplifying the rate of solution of "aerated" iron and by directly measuring the generated current of "aerated" metal surfaces (iron,

CORROSION TYPES & INFLUENCING FACTORS

• Factors Physical & Mechanical

3.5, 3.7

Relationship Between Coldworking and Hydrogen Embrittlement. C. A. Zapffe and M. E. Haslem. *Wire & Wire Prods.*, **23**, 475-478 + (1948) June.—BL.

3.5, 5.3, 5.4

Corrosion Fatigue. *Zinc Bull.*, **1949**, No. 6, 13.

The use of zinc coatings and paints heavily pigmented with zinc is advocated to avoid corrosion fatigue.—RPI.

ENVIRONMENTS

• Atmospheric

4.2, 6.3, 2.2

Effect of Weather on the Initial Corrosion Rate of Sheet Zinc. O. B. Ellis. ASTM Preprint, **1949**, No. 10, 11-26.

Sets of 6 x 4 in. zinc and iron specimens were exposed in a mild industrial atmosphere at monthly intervals. The agreement among the individual specimens in each set was satisfactory, but the average amount of corrosion of the zinc sets for 26 different 28-day periods varied by as much as 8:1. The max. variation for the iron was only 1.7:1. More than three-quarters of the variation in the weight losses for the zinc sheets could be attributed to the weather conditions during the first five days of exposure, there being a high correlation between the weight losses and the number of hours of rainfall, and the number of hours of high relative humidity conducive to condensation of dew. Other factors affecting the weight loss for the zinc, though to a much lesser extent, were the number of hours of rainfall and of 100% relative humidity after the first five days. The rate of attack after one year's exposure was still found to depend on the initial rate, and specimens which initially corroded rapidly were still corroding at a higher rate than those initially slowly attacked.—MA.

• Chemicals Inorganic

4.3

The Disposal of Spent Acid Pickling Liquor. W. B. Wraggs. *J. Iron Steel Inst.*, **162**, Pt. 2, 213-224 (1949) June.

A survey was made of methods for dealing with spent pickling acid, emphasis being laid on H_2SO_4 liquors. The neutralizing and crystallizing techniques associated with acid recovery are discussed. Continuous and bath treatment processes are discussed, and comparison is made between freezing and water-cooling as applied to crystallization methods. The problem of the disposal of ferrous sulfate, the by-product of acid-recovery processes, is considered. 18 references.—INCO.

• Chemicals Organic

4.4, 5.4

Protective Coatings for Fatty Acids. Fred L. Sharpe, Jr., and Kenneth Tator. *Chem. Eng.*, **56**, 230, 232 (1949) Sept.

Sharpe briefly describes use of phenol-formaldehyde resins to protect metallic surfaces against fatty-acid corrosion. Tator discusses use of various resinous coatings to prevent corrosion of metals by fatty acids.—BLR.

PREVENTIVE MEASURES

• General

5.1

Corrosion Preventives and Their Assessment. D. L. Samuel. *Scientific Lubrication*, **1**, 2 (1949); *J. Brit. Shipbuilding R. A.*, **4**, No. 3, 158 (1949).

The author describes some of the fundamental principles of their manufacture, testing and use.—RPI.

• Metallic Coatings

5.3, 6.2

Surface Treatment of Malleable Cast Iron. (In French.) Pierre Tyvaert. *Fonderie*, **1949**, 1626-1627, June.

Describes a new method of chemical tin coating of malleable iron, developed on a laboratory scale. Possibility of application on an industrial scale is indicated.—BLR.

5.3, 6.2

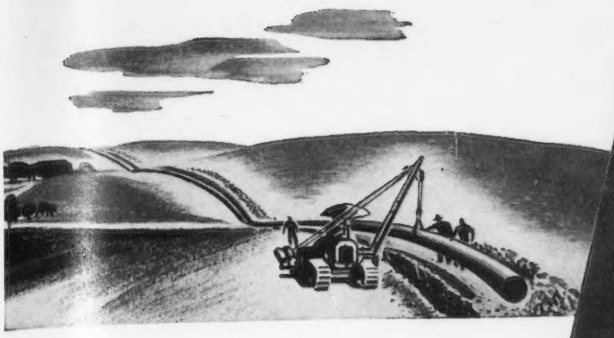
The Electroplating of Stainless Steels. R. Weiner. *Arch. Metallkunde*, **3**, No. 1, 38-42 (1949).

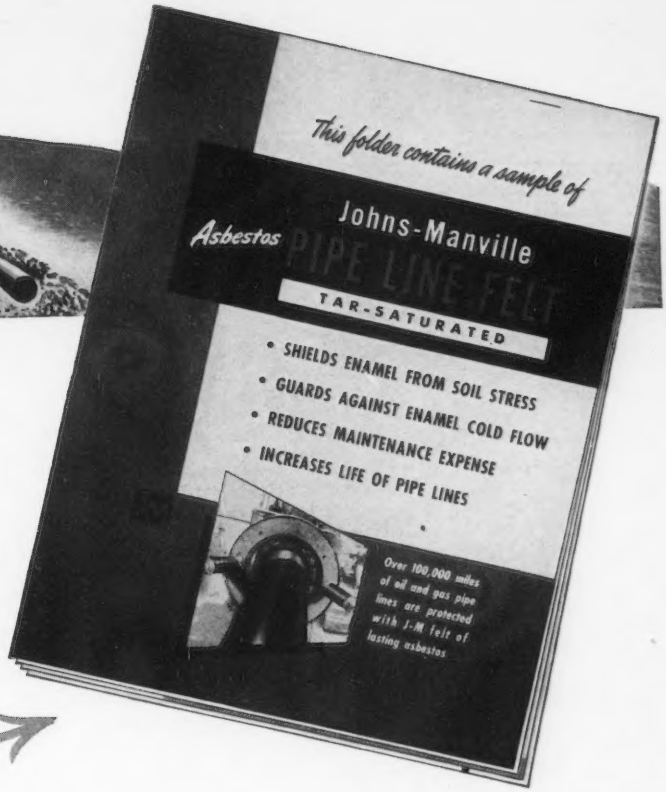
Stainless steels are electroplated either to increase their corrosion-resistance to particular reagents or for decorative effects; the usual deposits are silver and gold. W. discusses: a) methods for reducing the passivity of the steel surfaces in order that satisfactory deposits may be obtained, and b) recommended procedures for the deposition of heavy silver coatings on cutlery and for gold plating fountain-pen nibs.—MA.

5.3, 3.5

Oxidation of Titanium Carbide Base Ceramals Containing Molybdenum, Tungsten and Cobalt. M. J. Whitman and A. J. Repko, Lewis Flight Propulsion Lab. NACA Tech. Note No. 1914, July, 1949, 49 pp.

The oxidation-penetration characteristics of a number of titanium carbide base ceramals when exposed to temperatures of 1625, 1785 and 2000° F were investigated. A direct-measurement metallographic method was used to determine the depth of penetration. The various ceramals were composed of titanium carbide and 5, 10, 20 and 30 molybdenum, tung-

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sten or cobalt. The cobalt ceramals were considered better than the tungsten ceramals in overall oxidation resistance and the molybdenum ceramals were inferior to both the cobalt and tungsten ceramals. Graphs and photographs are shown. 8 references.—INCO.

• Non-Metallic Coatings

5.4

Zinc Oxide. Maas. and H. W. Talen. *Verfkroniek,* **22,** No. 5, 79-90 (1949).

A critical discussion of the CIMO exposure tests (*Review,* 1948, 421), with particular reference to the poor results obtained with zinc oxide paints.—RPI.

5.4

Flame Spraying of Metals and Plastics. *Mech. World,* **124,** 743-745 (1948) Dec. 31.—BL.

5.4

A Selective Coating System. *Mat. & Meth.,* **30,** 97 (1949) Sept.

Cyclon Series WPS, designed for the protection of all types of metals that are subjected to extreme corrosive conditions has been announced by Murray Products, Inc.—BL.

5.4, 4.2

Cementiferous Paints. Marine Exposure of Cementiferous Painting Schemes. J. E. O. Mayne, R. S. Thornhill and K. A. Pyefinch. *J. Iron & Steel Inst.,* **161,** Pt. 2, 100-2 (1949).

A dicussion of papers previously reported (*Review,* 1948, *232,* 248).—RPI.

5.4, 1.8

Mechanism of the Protective Action of an Unpigmented Film of Polystyrene. J. E. O. Mayne. Oil Col. Chem. Assoc. Conf., Rothesay, 1949, Preprint, 6 pp. *Oil Co. Trade J.,* **115,** No. 2644, 1558-9 (1949).

A polystyrene film interposes a high resistance to ionic currents between adjacent anodic and cathodic areas on a protected iron surface, but on immersion in sea-water this resistance is progressively reduced by absorption of water and, later, by inward migration of ions, with consequent acceleration of corrosion.—RPI.

5.4, 5.8, 1.8

Corrosion Inhibitive Action of Zinc Compounds. J. E. O. Mayne. *J. Soc. Chem. Ind.,* **68,** No. 9, 272-274 (1949) Sept.

Description of investigation to establish the way in which various zinc pigments inhibit corrosion. Zinc dust, zinc oxide, and lithopone were not capable of rendering water non-corrosive. When ground in linseed oil the corrosive nature of the water was diminished, but complete inhibition was obtained only with zinc linoleate and with one sample of zinc dust. Inhibition was brought about by soluble zinc compounds produced by hydrolysis of zinc soaps. The majority of zinc pigments were not efficient inhibitors owing to their inadequate soap forming properties. Mechanism of inhibition is discussed, and the view is put forward that the soluble zinc compounds are adsorbed on the metal surface, and act as an anodic inhibitor.—INCO.

5.4

How to Select Inorganic Finishes. W. R. Meyer. *Steel,* **123,** 112-114+ (1948) Dec. 6.—BL.

5.4

Electrostatic Spraying Process. E. P. Miller. *Org. Fin.,* **9,** 136-139 (1948) Apr. —BL.

5.4, 6.5

Solar Radiation. M. G. J. Minnaert. *Verfkroniek,* **22,** No. 3, 48-9 (1949).

The nature of solar radiation, its variation with the season and height of the sun, and the effects produced by it, are discussed with reference to the weathering of paints, rubber, asphalt and plastics.—RPI.

5.4

Shop Primers Important to Process Plant Paint Programs. J. W. Nee, Napko Paint & Varnish Works. *Petro. Ref.,* **28,** No. 10, 107-110 (1949) Oct.

Emphasis on necessity for proper paint specifications for shop coats and metal preparation of fabricated pressure vessels includes repriming, shop inspection and cost of protection. Photographs of corroded test panels are included.—INCO.

5.4, 7.5

Chromasoid Corrosion-Proof Lining. *Oil & Gas J.,* **48,** No. 19, 139-140 (1949) Sept. 15.

Chromasoid is a new low-cost lining material for corrosion prevention on all Schaub condensate tanks and return system receivers. Chromasoid, a successful formulation of a furfuryl alcohol resin, is chemically inert as far as is known. It is black and dries to a hard glossy finish with the appearance of porcelain. It has sufficient flexibility when used with a special primer to maintain adhesion to metal surfaces even under severe thermal shock. Mfd. by Fred H. Schaub Eng. Co., Inc.—INCO.

5.4

Use of Anti-Rust Paint Against the Corrosion of Structural Metalwork. P. Pessi. *Hommes et Techniques,* **1948,** 37-39, July-Aug.; *Mecanique Documentation,* **3,** Oct. 6 (1948); *J. Iron & Steel Inst.,* **161,** Pt. 4, 267 (1949).

A description is given of studies made by the Office Technique pour l'Utilisation de l'Acier to improve the protection against corrosion of present-day commercial steels.—RPI.

5.4, 1.1

Protecting Metals with Organic Paint Coatings. *Prod. Fin.,* **1949,** 70+ Mar.; *Prod. Fin.,* **2,** No. 6, 86 (1949).

The mechanism of corrosion is discussed generally and the functions of primer and finishing coats are outlined. —RPI.

5.4

Future Trends in Alkyd Resins for Protective and Decorative Coatings. *Prod. Fin.,* **12,** 80+ (1948) Aug.—BL.

5.4

New West Linn Mill Creates Two New Industries. *Pulp & Paper,* **22,** No. 7, 33-40 (1948) June.

Framework of Fourdriner is covered with stainless steel and care was taken to guard against corrosion and maintain max. degree of cleanliness. Bird screens discharge into a flow box of steel construction. Monel lined, and Monel lined sluice and headbox. Consistency regulators are mounted in stainless steel boxes and all pipe lines are of stainless construction.—INCO.

5.4

Basic Zinc Chromate as an Anti-Corrosive Pigment. H. Rabaté. *Chim. Peint.,* **12,** No. 5, 164-9; No. 7, 286-92 (1949).

A review of the different pigts. available for use in paint under the general heading of basic zinc chromate. Although various theories have been put forward to account for the properties of anti-corrosive pigts. in general and chromates in particular, the matter is not yet elucidated. The following factors play a part: alkaline nature, oxidizing properties, soap formation (zinc soaps are considered less effective than lead soaps in modifying film tension), water movement (red lead offer resistance; a certain passage is possibly required for effective anti-corrosive action with chromates). Analytical results are given for a) zinc yellows (French and English manufacture) b) tetrahydroxychromate (U. S. origin), and c) trihydroxychromate; a) corresponded to $K_2O,^4ZnO,$ $^4CrO_3,$ ^3H_2O, (b) to $ZnCrO_4,$ $^2Zn(OH)_2$ and c) $ZnCrO_4,$ $^3Zn(OH)_2$. ZnO content and water solubility are important. The trihydroxychromate is easily prepared and has low water solubility.—RPI.

5.4

Use of Lime in Glazes, Paints and Waxes. H. Rabaté. *Peint. Pig. Vernis,* **25,** No. 2, 51-2 (1949).

The uses of lime and its compds. in paints are described together with the prepn. of suitable whitewashes for use as undercoats, anti-corrosive disinfectants, and as a protection against sea air, sea water and H_2S.—RPI.

5.4, 3.3, 2.3

Fungicides and Fungicidal Paints. H. Rabaté. *Peint. Pig. Vernis,* **25,** No. 5, 169-70 (1949).

The properties desirable in a fungicide are listed and many substances mentioned, together with short notes on their efficiency; laboratory tests, and methods of employment.—RPI.

5.4

Anti-Rust Coatings Based on Cement. H. Rabaté. *Peint. Pig. Vernis,* **24,** No. 10, 305-6 (1948).

Literature on the prepn. of anti-rust coatings containing cement is surveyed. —RPI.

5.4

Rust Preventative. *Railway Mechanical Eng.,* **123,** No. 10, 591 (1949) Oct.

A rust inhibitor named EWH Formula and utilized for the protection of metals against rust, corrosion, pitting and tarnish. It provides a tough, transparent and colorless coating that will withstand weather, heat, cold, grit, grease, etc. It can be removed with standard acetates. It is not a plastic and is claimed not to discolor or turn brown. Formula can be applied by brushing, spraying or dipping and dries in 2 minutes. Mfd. by Temperature Equipment Corp.—INCO.

5.4, 6.5

Protective Coatings and Caulking Materials for Roofs. A. W. Rick. *Farben, Lacke, Anstrichstoffe,* **3,** No. 5, 146-8 (1949).

Problems connected with the painting

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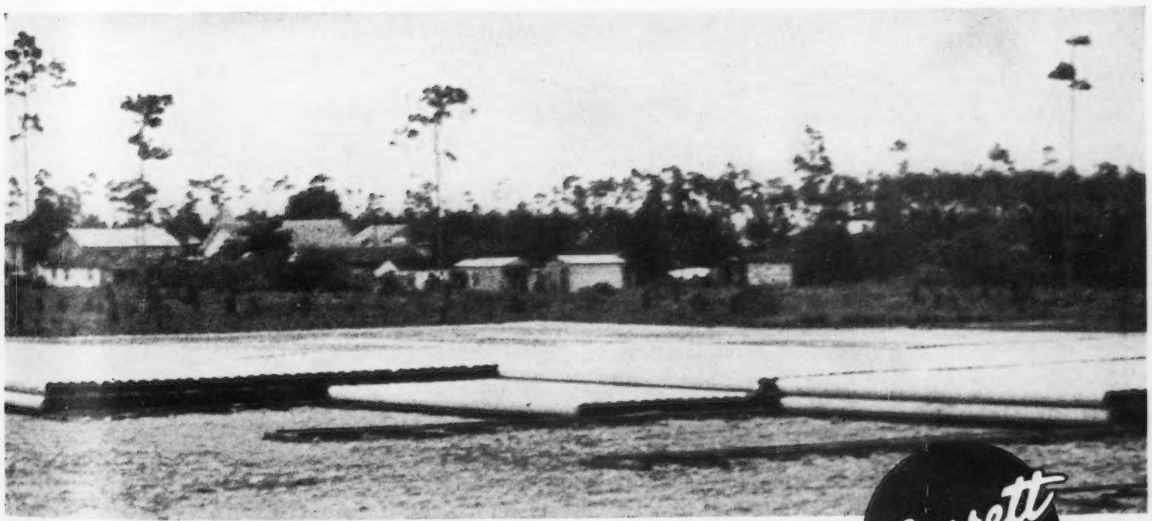

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of roofing felt and bitumen and tar caulking materials are discussed.—RPI.

5.4

Protection of Iron by Paint. B. F. H. Scheifele. *Farbe u. Lack*, **55,** No. 5, 157-8 (1949).

A commentary on a paper by Ragg, M. (**Elektrotechnik u. Maschinenbau, 64,** No. 9-10, 150-60.

Topics considered are the importance of pigment/binder interaction, and corrosion-inhibitive pigments, particularly the newer pigments.—RPI.

5.4

Varnish—Shining Protection. C. H. Schrepfer. *Can. Pt. and Varnish*, **22,** 42-43 + (1948) May.—BL.

5.4

Finishing Materials. Properties of Synthetic Coatings. F. L. Scott. *Org. Fin.*, **9,** 39 + (1948) Apr.—BL.

5.4, 4.3, 4.4, 4.6

Protective Coatings. G. E. Seidel. *Steel Proc.*, **35,** 368-370 (1949) July.

Outlines procedures for surface preparation and application of the coatings developed by Amercoat Div., American Pipe and Construction Co., Chicago, for steel structures exposed to water, alkali, salt and petroleum.—BLR.

5.4, 3.5

High-Temperature Ceramic Coatings for Steel. *Steel Proc.*, **34,** 245-247 (1948) May.—BL.

5.4, 1.3

Modern Rust-Protective Paints. G. Tengstrand. *Farg och Fernissa*, **13,** No. 1, 11-4 (1949).

A review.—RPI.

5.4, 2.3

Corrosion of Metals Under Lacquer Films and Electrochemical Methods of Investigation of Protective Properties of Lacquer Coatings. (In Russian.) N. D. Tomashov, V. S. Kiselev, and M. M. Gol'dberg. *Izvestiya Akademii Nauk SSSR, Otdelenie Khimicheskikh Nauk.* (Bulletin of the Academy of Sciences of the USSR, Section of Chemical Sciences), **1949,** 152-163, Mar.-Apr.

Develops basic laws of the above corrosion process. On the basis of the results, an electrochemical method is proposed. Method of investigation is described and typical data are tabulated and charted. 17 ref.—BLR.

5.4, 3.5

High-Temperature Ceramic Coatings for Molybdenum. *U. S. NBS., Tech. News Bull.*, **32,** 125-126 (1948) Nov.—BL.

5.4

Theoretical and Practical Considerations Affecting Organic Coatings Used for Protection Against Corrosion. G. H. Young. *Metaux et Corrosion*, **23,** No. 278, 232-241 (1948).

Y. lists organic resins used for the protection of metals from corrosion and describes the physical and chemical properties desirable in them. Among the important factors are the continuity of the film, its permeability to moisture, and its adhesive and cohesive properties; the relations between these factors and the molecular structure of the resin are discussed. Y. concludes by discussing a number of practical considerations.—MA.

• Packaging

5.6, 5.8

Corrosion Prevention for Metals. *Petro.*, **12,** 180 (1949) July.

A powerful corrosion inhibitor has recently been introduced for preventing corrosion of iron and steel and other metals, between manufacturing steps, in packages for shipment and during storage. It is a synthetic chemical with unique properties that make possible an entirely new method of corrosion-preventive packaging. The compound is a white crystalline stable organic compound which very slowly sublimes or vaporizes. The vapor, which is odorless, non-toxic and non-injurious to the skin, completely surrounds any article in an enclosed space and prevents corrosion. Direct contact of the substance with the metal is not necessary. It acts by forming an invisible, thin, protective film on the surface of the metal and this film is maintained as long as the inhibitor is present in the atmosphere. The new product may be applied in powder form or in solution in water or alcohol, but the most convenient and economical method is the use of coated wrapping materials. The inhibitor is claimed to be outstanding for corrosion protection of ferrous metals and for such metals as aluminum, duralumin, cast iron and chromium plate.—TIME.

5.6, 5.3, 5.4, 5.5

The Corrosion-Protection of Idle Machinery and Apparatus. B. Scheifele. *Arch. Metallkunde*, **2,** No. 9, 322-323 (1948).

A brief review. Greases and fats are good protective agents for iron and steel, as well as for polished aluminum and light alloy parts. Lacquers, special cements, and electrochemically deposited coatings of zinc or cadmium are also suitable.—MA.

5.6

Gas Attack on Rust. New Synthetic Chemical Offers Packagers Unique Anti-Corrosion Weapon. Shell Development Co. *Chem. Ind.*, **63,** 590 (1948) Oct.—BL.

5.6, 5.4

New Anti-Corrosive Lacquer. I. V. Vodzinskii. *Stanki i Instr.*, **1948,** 25, Feb.; *Mecanique Documentation*, **3,** 3 (1948); *J. Iron & Steel Inst.*, **161,** Pt. 3, 266 (1949).

Details are given of a new lacquer for protecting machine tools against corrosion during transit. The compn. is N.C. 35% by wt., camphor 20%, drying oil 5%, acetone 40%. Parts protected by this lacquer showed no trace of corrosion after two weeks in an acid or basic atmosphere.—RPI.

• Inhibitors (Passivators)

5.8, 1.8

Mechanism of Inhibition of Corrosion of Iron by Chromic Acid and Potassium Chromate. J. E. O. Mayne and M. J. Pryor. *J. Chem. Soc.*, **1949,** 1831-5, July.

An examination has been made of the mechanism by which the corrosion of iron is inhibited by aerated solns. of CrO_3 and K_2CrO_4. The view is put forward that the iron ions are oxidized, while still in the solid lattice, to γ-Fe_2O_3 oxide, which forms a thin continuous film on the iron. This film is impervious to iron ions, and thus corrosion is prevented.—RPI.

5.8

Inhibitors. (In German.) *Metalloberflache*, **3,** June, A125 (1949).

Briefly describes preparation of some corrosion inhibitors said to be especially effective. Full details necessary to prepare these mixtures are given.—BLR.

5.8, 6.5

Metallic-Oxides as Barrier Treatments for Prevention of Attack by Light on Cellulose. S. L. Perti, S. K. Ranganathan, T. S. Subraman, and L. R. Sud. *Nature*, **163,** No. 4153, 877-8 (1949).

Manganese oxides deposited on fabrics inhibit actinic degradation; copper oxide accelerates it.—RPI.

5.8, 4.6

The Effect of Acid and Neutral Phosphate Solutions on Ingot Steel. G. Seelmeyer. (In German.) *Archiv fur Metallkunde*, **3,** 289-294 (1949) Aug.

The corrosive effects of phosphates added to the water in hot-water heating plants was investigated to determine whether the phosphate ion alone or only in conjunction with other ions has a passivating effect. Potentials, measured and correlated with phosphate concentration and time, indicate that neither phosphate ions alone nor $FePO_4$ films at pH values of 8.8 have a sufficient passivating effect to account for the corrosion-inhibitive effect of phosphates. This is believed to be caused by formation of a protective lime deposit. Diagrams, graphs, and tables. 11 ref.—BLR.

5.8

On Sodium Metaphosphate. W. Teichert and K. Rinman. (In German.) *Acta Chem. Scandinavica*, **2,** No. 3, 225-251 (1948).—BL.

Bibliography.

5.8, 4.6, 6.2

Sodium Nitrite as an Inhibitor Against the Attack of Sea Water on Steel. Part II. The Addition of Other Inhibitors to Nitrite. D. Wyllie and G. C. N. Cheesman. *J. Soc. Chem. Ind.*, **68,** 209-212 (1949) July.

Efficiency and probable mode of action of phosphates, carbonate, sulfates, and zinc salts are described. Data are charted. 10 ref.—BLR.

• Surface Treatment

5.9, 7.1

British Chromizing Development. *Electroplating*, **3,** No. 2, 52 (1949) Oct.

Development of a chromizing process in which steels of normal types are provided with an outer layer several thousandths of an inch thick, containing about 30% chromium, by high temperature diffusion of chromium. Chemical characteristics of the metal are those of its surface. Chromizing provides resistance to scaling and oxidation at high temperature and to many types of corrosion; chromized steel is claimed to withstand immersion in water for indefinitely long periods without rusting and to be unaffected by moisture and smoke in the atmosphere. Most spectacular application of the process to date is in jet engines and gas turbines. Mfd. by Metal Gas Co., Ltd.—INCO.

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5.9, 6.4
Anodic Oxidation of Aluminum. *Electroplating,* **1,** 535-536 (1948) Aug.—BL.

5.9
Driving and Controlling Modern Strip Pickling Line. J. R. Erbe. *Iron Age,* **163,** 46-50 (1949) Jan. 13.—BL.

5.9
Abrasive Blasting as a Surface Preparation. J. F. Farrell. *Org. Fin.,* **9,** 18-21 + (1948) Dec.—BL.

5.9
Abrasive Blasting Applications. J. F. Farrell. *Die Castings,* **7,** 45-46 + (1949) Sept.
Describes the above as applied to die castings. Three applications include: surface preparation before painting, removal of flash and burrs, and elimination of symptoms of porosity.—BLR.

5.9
Metal Cleaning. (In Swedish.) *Finish (Sweden),* **6,** 33-36 +, 55-58 + (1949) Feb.-Mar.
Discusses the cleaning of metals by electrolysis, alkalies, solvents, emulsions, and petroleum derivatives, by etching with acids and electrolytically, and by mechanical methods. Illustrated.—BLR.

5.9, 6.2
An Investigation of Structural Steel Shop Coat Priming Paint. S. C. Frye. *Corrosion,* **5,** 288-291 (1949) Sept.
Presents test results for 17 paints using 3 types of pigmentation on structural steel in different conditions: as received from the mill, pickled in inhibited acid, and after different degrees of rusting followed by scale removal.—BLR.

5.9, 5.8
Subsequent Treatment of Phosphate Coatings With Chromates. W. Machu. (In German.) *Archiv fur Metallkunde,* **3,** 250-253 (1949) July.
The porosity of phosphate films is reduced by treating with Na_2CrO_4, $K_2Cr_2O_7$ or H_2CrO_3. Chromate-treated phosphate coatings have an increased electrical resistance not only because of their reduced porosity, but also because of the passivating effect of the chromate in the pores of the protective film. Includes graphed and tabulated data.—BLR.

5.9
Porosity and Formation Rate of Electrophosphate Films. W. Machu. (In German.) *Archiv fur Metallkunde,* **3,** 278-281 (1949) Aug.
Proves that AC treatment accelerates the Bonderizing action even in baths which already contain powerful accelerators. The slightly greater porosity of electrophosphate films is explained and it is suggested that such films may have a greater protective effect than other types. Data are graphed and tabulated. 14 ref.—BLR.

5.9, 5.8
Manganese Phosphate Films From the "Short-Time" Bath. W. Machu. (In German.) *Archiv fur Metallkunde,* **3,** 283-286 (1949) Aug.
The rate of formation and porosity of phosphate films produced by NO_3-containing manganese-phosphate baths was investigated by an electrochemical method. Results show that a fresh bath will result in greater porosity than a used bath. Treating the Bonderized metal in a chromate bath further increases its already good corrosion resistance. Includes tabulated and graphed data.—BLR.

5.9
Anodic Oxidation. Reactions of Aluminum in Sulfuric and Oxalic Electrolytes. *Metal Ind., Lond.,* **72,** 383 (1948) May 7.—BL.

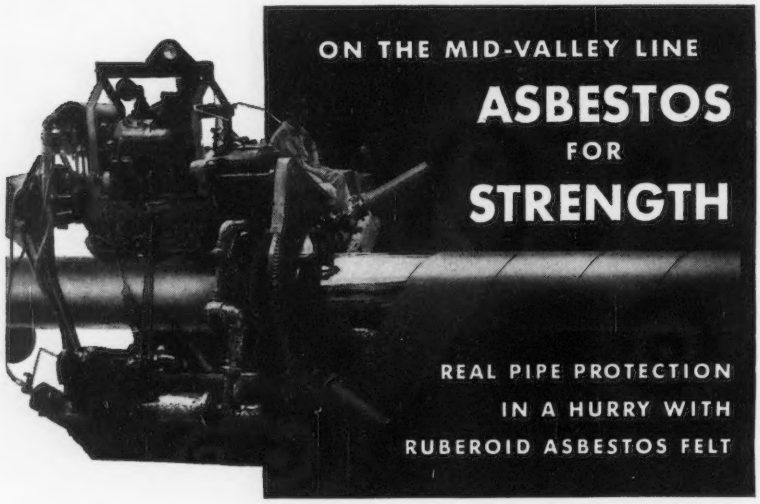
5.9
Metal Cleaning. Eng. Data Sheet. *Metal Fin.,* **46,** 113 (1948) June.—BL.

5.9
Detergents, Wetting and Emulsifying Agents. Their Use in Metal Cleaning. *Metallurgia,* **38,** 37 (1948) May.—BL.

5.9
Phosphatizing of Sintered Iron. *Metalloberflache,* **2,** 173-4 (1948) Aug.; *J. Iron & Steel Inst.,* **1949,** Pt. 2, 159.
The process of Bonderizing sintered iron products is briefly described. It is done in five stages, viz., degreasing, rinsing, Bonderizing, rinsing in cold and then hot water, and drying. The corrosion resistance of sintered iron phosphatized by this method is equal to that of the cast metal.—RPI.

5.9
Preparation of Metals for Organic Finishing. *Org. Fin.,* **9,** 12-17 (1948) Apr.—BL.

5.9
Chemical Polishing Puts Ax to Finishing Costs. *Modern Ind.,* **18,** 95 (1949) Sept. 15.
Describes patented method developed



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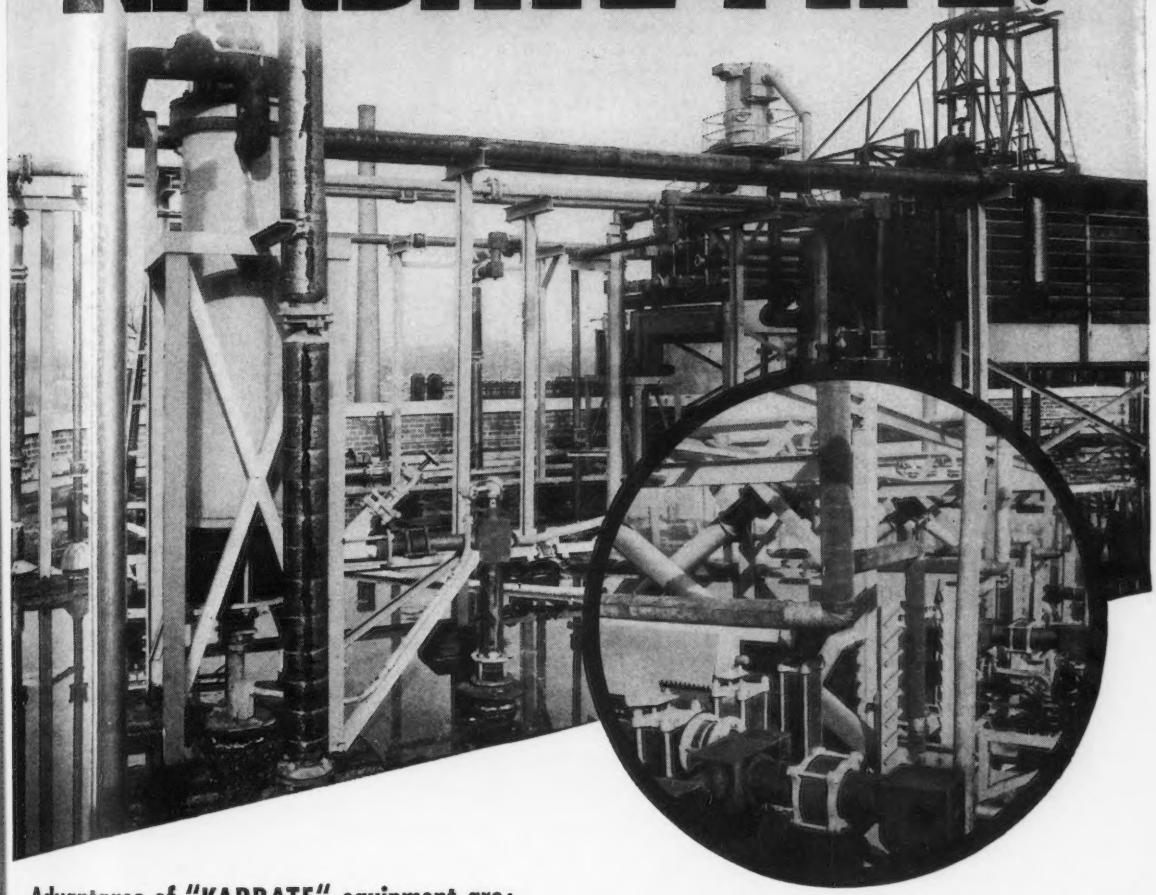

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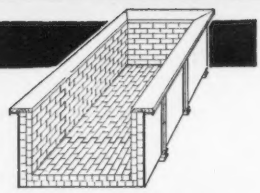

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5.9

Chromizing Process as Developed and Used by Diffusion Alloys, Limited, of London. C. A. Naugle, AMC *Tech. Data Dig.*, **14**, No. 21, 13-19 (1949) Nov. 1.

The chromizing process recently developed by Diffusion Alloys, Ltd., is essentially the same as the German process, employing the principle of an atom exchange between iron and chromium at high temperature. However, the method is different in that articles to be chromized are packed in carburizing pots; the use of retorts and hydrogen chloride jets is eliminated by a ferrochrome kaolin powder to which a halide is added to form chromous iodide, which in turn allows diffusion of chromium to occur at relatively low temperatures (1850°-2150° F). The chromium alloyed surface

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State of Texas, County of Harris.

Before me, a notary public in and for the State and county aforesaid, personally appeared A. B. Campbell, who, having been duly sworn according to law, deposes and says that he is the business manager of CORROSION and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management of the aforesaid publication for the date shown in the above caption, required by the act of August 24, 1912, as amended by the acts of March 3, 1933, and July 2, 1946 (section 537 Postal Laws and Regulations), printed on the reverse of this form, to wit:

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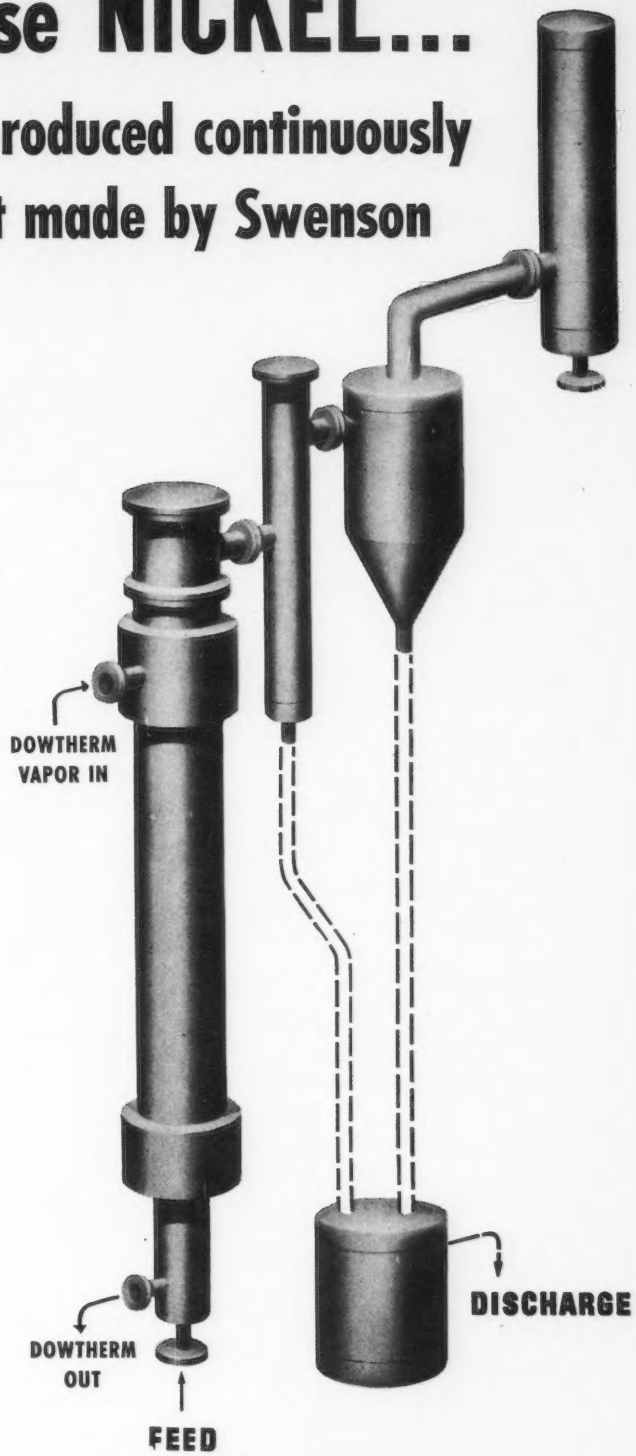

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5.9

Sodium Hydride Descaling. A. Normand. *Galvano,* **135,** 9-10 (1948).

A description of sodium hydride process for removing surface oxide layers from all ferrous metals and their alloys, the precious metals, chromium, nickel, and copper. It cannot be used for aluminum, magnesium, zinc, cadmium, lead, tin, and their alloys. In essentials, the process consists of immersion in molten caustic soda containing 1.5-2% sodium hydride (at 370° ± 7° C) followed by a cold-waterdip. The equipment, economics, and advantages are discussed.—MA.

5.9

Metal Cleaning With Acid. *Prod. Fin.,* **2,** No. 4, 16-8 (1949).

Acid cleaning, while far from the ideal method of preparing metals for the deposition of coatings, still remains the most economic process. The most serious defect in acid processing is H_2 embrittlement, which is avoided by placing the processed material in a drying chamber for approx. 4 hr. at a temp. of 200-250° C followed by a few hours standing. Composition of pickling baths for aluminum bronze and cupro-nickel articles are given.—RPI.

5.9

Diphase Metal Cleaners. Preferential Wetting by the Two Phases. L. Reich and F. D. Sneel. *Ind. & Eng. Chem.,* **40,** 1233-1237 (1948) July.—BL.

5.9, 5.4, 5.3, 6.4

The Surface Treatment of Light Metals. Franz Ritter. *Berg. u. Huttenmann. Monatsh. Montan. Hochschule Leoben,* **93,** Nos. 8/11, 208-211 (1948).

Presented at the Second Light Metals Symposium, Leoben, June, 1948. Mechanical (polishing), chemical, electrochemical, cladding, and lacquering methods for improving the corrosion-resistance of light-metal alloys are discussed.—MA.

5.9, 6.4

The Eloxal Process. Franz Solar. *Berg- u. Huttenmann. Monatsh. Montan. Hochschule Leoben,* **93,** Nos. 8/11, 211-214 (1948).

Presented at the Second Light Metals Symposium, Leoben, June, 1948. The Eloxal (anodic oxidation) process is described, details being given of: 1) types of baths and operating conditions, 2) necessary degreasing, cleaning and finishing treatments, and suitable lay-out of the plant required, 3) the thickness, mechanical and corrosion-resistant properties of the films produced, and 4) commercial applications of the finished material.—MA.

5.9

The "Inkrom" Process. F. Steinberg. (In German.) *Archiv fur Metallkunde,* **2,** No. 8, 253-254 (1948).

Describes briefly a chromizing process for converting the surfaces of ordinary steel parts into high-test, rust-resistant steel. Includes photomicrographs and graphed data.—BLR.

5.9

Shot Peening. J. Straub. *SAE J.,* **56,** 37-38 (1948) Nov.—BL.

5.9, 1.8

Isotherms at 100° C of the System: MnO-P_2O_5-H_2O. S. S. Taperova and M. M. Isaeva. (In Russian.) *Zhurnal Prikladnoi Khimii* (J. of Applied Chemistry), **22,** 342-353 (1949) Apr.

The above was investigated because of its importance in connection with phosphating for corrosion protection of ferrous metal. Data are tabulated and charted. 30 ref.—BLR.

5.9, 1.3

Cleaning and Finishing. Arch B. Tripler, Jr. *Metals Rev.,* **21,** No. 6, 3, 5, 7 (1948).

A review of developments in cleaning, metal coatings, barrel finishing, polishing, buffing, grinding, anodizing, and coloring.—MA.

5.9, 6.3

Bronzing of Brass. Pierre Tyvaert. *Foundry Trade J.,* **87,** 249 (1949) Aug. 25. Translated from Fonderie.

Outlines surface preparation, surface treatment, and drying procedures. Table gives details for those which have worthwhile results as to color and adherence. —BLR.

5.9, 6.4

Surface Treatment and Finishing of Light Metals. I-II. S. Wernick and R. Pinner. *Sheet Metal Ind.,* 26, No. 263, 585-93, No. 264, 805-10 + (1949); *Electroplating,* **2,** No. 6, 429 (1949).

The authors deal with some of the

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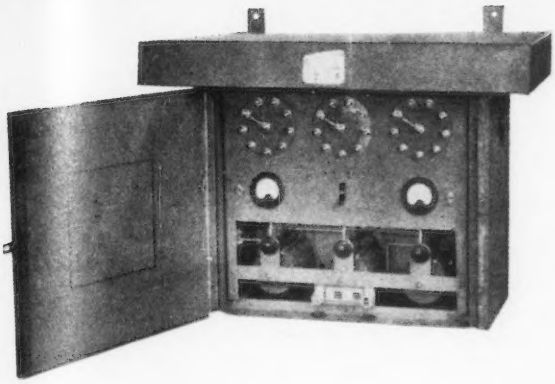

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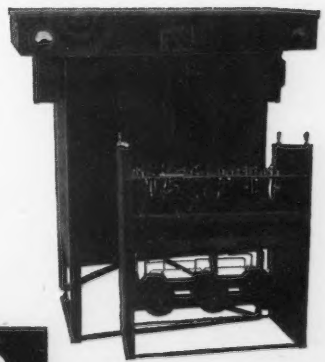

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properties of certain alloys which may be encountered in practice and the choice of protective and decorative treatments and finishes. The corrosion and protection of aluminum and its alloys are discussed.—RPI.

5.9, 6.4

Surface Treatment and Finishing of Light Metals. III. S. Wernick. *Metal Ind.*, **1949**, 1289-95; *Prod. Fin.*, **2**, No. 7, 68 (1949).

The corrosion and protection of aluminum and its alloys is discussed.—RPI.

5.9, 1.8

Adsorption and Absorption of Surface Films, Especially Phosphatic Films, and Their Plasticity. H. Wüstefeld. (In German.) *Archiv fur Metallkunde*, **3**, 223-224 (1949) June.

Discusses the physicochemical principles of Bonderizing and shows that the properties of a given phosphate film depend to a large extent on the conditions of formation. Tests which demonstrate the adsorption of soap by the phosphate film and the deposition of films on clean uncoated and on Bonderized metal surfaces are described.—BLR.

5.9, 1.8

Theory of Phosphating. A. Wüstefeld. (In German.) *Archiv fur Metallkunde*, **3**, 253-255 (1949) July.

Shows that the theoretical principles of phosphating in acid and in alkaline baths are the same. In both cases, the removal of hydrogen or hydroxide ions in excess results in formation of colloids with charges opposite that of the attacked metal and, thus, in strong adherence of the film to the metal. A method for phosphating aluminum is presented. —BLR.

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6.2, 3.7

Investigations of Corrosion-Resistant Cast Steel with a Chromium-Nickel Base with Special Consideration of the Sigma Phase. W. Felix and E. Eisermann. (In German.) *Schweiz. Arch.*, **15**, 84-92 (1949) Mar.

References.—BL.

6.2

Molybdenum-Bearing Stainless Casting Alloy Has Wide Range of Uses. Norman S. Mott. *Mat. & Meth.*, **30**, 50-53 (1949) July.

Describes corrosion-resistant, physical, and mechanical properties of alloy with improved corrosion resistance and increased strength at elevated temperatures. Applications are described and illustrated. 13 ref.—BLR.

6.2

High Strength, Low Alloy Steels. *Prod. Eng.*, **20**, 89-95 (1949) Oct.

Describes composition, properties, forming characteristics, corrosion resistance, heat treatment, and applications of the above. Data are tabulated and plotted. Illustrated.—BLR.

6.2

Steel Containing 8-9% Nickel: Mechanical Properties at Low Temperatures; Corrosion Resistance. P. Puel. (In French.) *Metaux & Corrosion*, **24**, 118 (1949) Apr. From *Revue du Nickel*, 1949, No. 2, 32.

Describes the above at temperatures as low as —200° C. Composition, optimum heat treatment and mechanical properties are indicated in tabular form. —BLR.

6.2

Magnetic Properties of Cast Stainless Steel. E. A. Schoefer. *Alloy Casting Bull.*, **1949**, No. 13, Aug. pp. 1, 4, 6.

Discusses various alloy types and describes reasons for their differences from wrought compositions, and shows that corrosion resistance is not a function of magnetic properties. Data are tabulated and plotted.

6.2, 2.2, 3.5

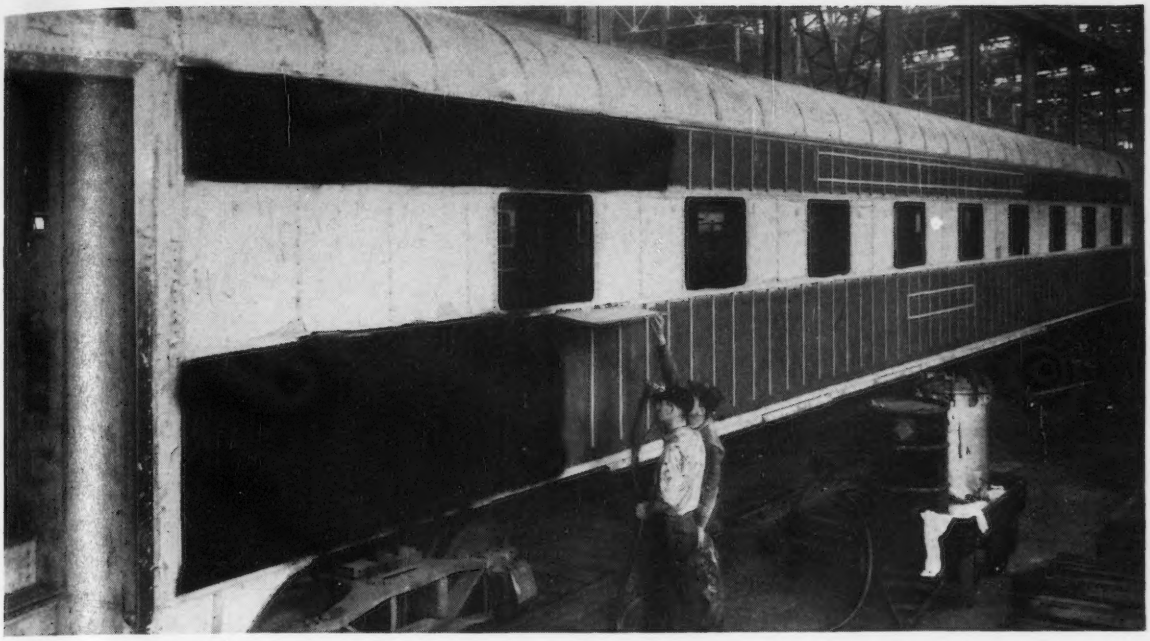
Stability of AISI Alloy Steels at Elevated Temperatures. A. B. Wilder and J. O. Light. ASM, Preprint No. 17, 1949, 19 pages.

Stability of over 100 different types at 900, 1050, and 1200° F is being evaluated over a period of 10 years. Results obtained in an examination of 16 of these steels for evidence of structural changes, oxidation characteristics, and impact properties after exposure for 10,000 hours are presented.—BLR.

6.2, 4.4

Solving Corrosion Problems with Lead and Tin Die-Castings. *Die Castings*, **7**, No. 2, 22 + (1949).

The use of lead and tin die-castings in label pasters, i.e., under conditions where they are subject to corrosion from glue, etc., is described.—MA.



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• Non-Ferrous Metals Heavy

6.3

Titanium—The Metal With a Future. *Eng. & Min. J.*, **150,** 119-123 (1949) July.

Discusses future prospects for commercial utilization of titanium. Includes brief appraisal of titanium's properties and potential uses by H. C. Cross of Battelle Memorial Institute and a survey of ore reserves.—BLR.

6.3

Corrosion Resistance, Applications and Other Properties of Titanium and Its Alloys. M. G. Fontana. *Ind. & Eng. Chem.*, **41,** 103A-104A (1949) Feb.

A symposium.—BL.

6.3

Noble Metals and Their Alloys. III—On Our Knowledge of the Chemical (Corrosion) Properties of Noble Metals and Their Alloys. E. Raub. (In German.) FIAT Rev. German Sci., 1939-1946: Non-Ferrous Metallurgy.—II, **1948,** 28-30.

A brief review, with references, of the corrosion and stress-corrosion properties of gold-silver, gold-copper, silver-copper, gold-silver-copper and gold-nickel-copper alloys. The effects of composition, especially solid solution formation, of ordering, and working and annealing are discussed.—MA.

6.3

Uranium (Production and Properties). W. Schulenburg. (In German.) FIAT Rev. German Sci., 1939-1946: Non-Ferrous Metallurgy. I, **1948,** 35-36.

The production of metallic uranium by the reduction of uranium oxide (U_3O_8) with calcium is reviewed. After grinding and purifying, the resulting product, containing 97% uranium, can be melted at 1400° C, in a high vacuum (0.001 mm mercury) using an electric furnace, and then cast in a graphite mold. The cast metal contains uranium 98.35, uranium oxides and nitrides 1.60, and iron 0.05%; it has a sp. gr. of 18.6, a m.p. of 1102° C, and a b.p., in vacuo, of 1480°-1500° C. The metal is brittle (owing to its oxide content) and can be worked only by rolling with small reductions and constantly annealing.—MA.

6.3

Less Common Metals. H. H. Uhlig and D. B. Broughton. *Ind. & Eng. Chem.*, **41,** 2153-2154 (1949) Oct.

Reviews recent publications on titanium, zirconium, tantalum, molybdenum, gold, platinum, and silver covering for the most part properties and applications. 67 ref.—BLR.

6.3, 4.7, 3.5, 8.8

The Precious Metals in Industry. E. M. Wise. *Metaux et Corrosion*, **25,** No. 284, 87-117 (1949).

A comprehensive review of the production, fabrication, properties and applications of the precious metals and a large number of their alloys. The mechanical properties and corrosion properties, including the attack by fused salts, of the materials are described in some detail. The uses are discussed of the precious metals a) as safety discs in chemical apparatus, b) in applications requiring resistance to corrosion at elevated temp., c) in electrolytic processes, d) in dentistry, e) as catalysts, f) in the manufacture of artificial silk, and g) as electrical contacts. A bibliography of 56 references is given.—MA.

• Non-Ferrous Metals Light

6.4

Corrosion-Resistant Aluminum-Magnesium Alloys. *Engineering*, **166,** 44-47 (1948) July 9.—BL.

6.4, 3.7

On the Production of Aluminum-Magnesium (6-7%) Alloy Products Resistant to Stress-Corrosion. E. Mohr. *Arch. Metallkunde*, **3,** No. 3, 117-118 (1949).

Heterogenization processes for improving the stress-corrosion resistance of aluminum-magnesium alloys are discussed, especially the method of Siebel and Vosskuhler (cf. *Met. Abs.*, **16,** 391 [1949]). Such methods are unsuitable for alloys containing 6-7% magnesium, as the necessary heat-treatment usually causes homogenization to occur and the final product has a low stress-corrosion resistance. A fundamentally new method is described for the successful treatment of such material. It consists of maintaining a slight heterogeneous structure throughout all the forging or rolling processes; if this is done, only a short anneal is necessary to produce soft or half-hard material direct from hard-rolled sheets, the finished material having a heterogeneous structure. Loop specimens of such material (aged for 24 hr. at 120° or 150° C) after alternating immersion in sea water for a year

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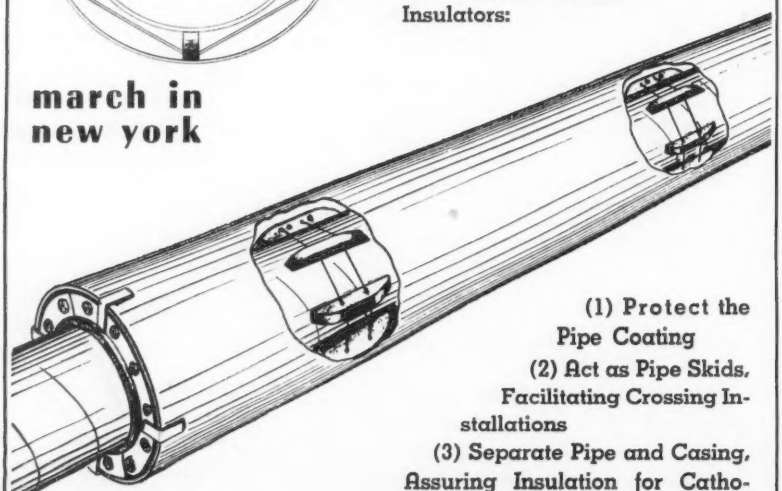

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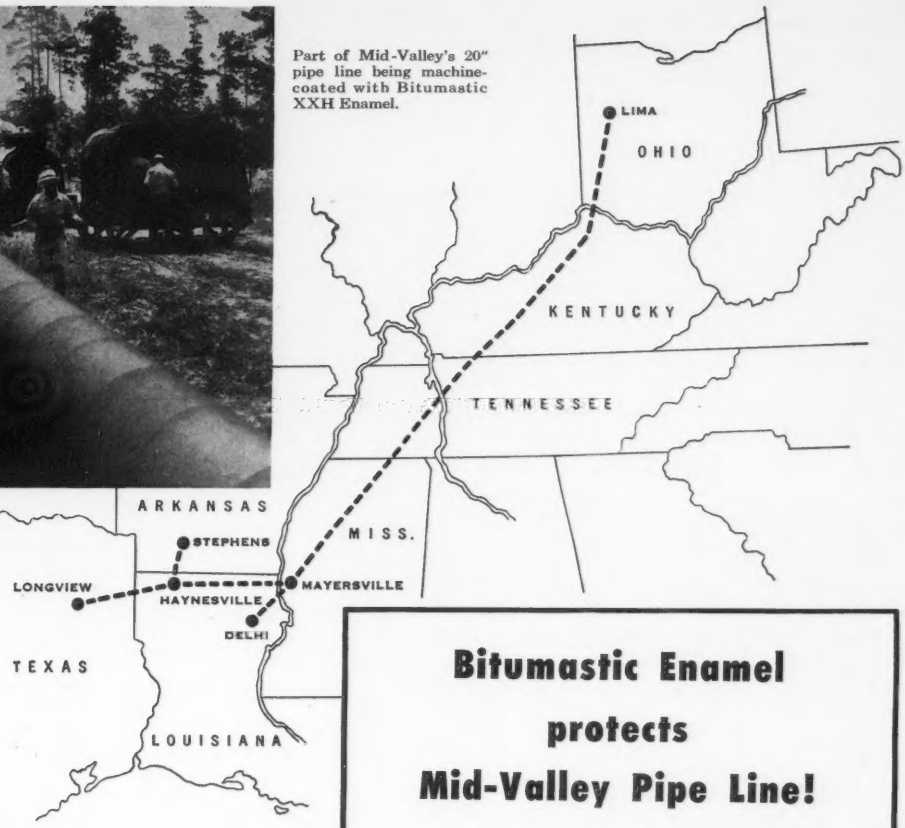

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showed no deterioration in corrosion or stress-corrosion-resistance.—MA.

6.4, 8.4

Use of Aluminum in the Petroleum Industry. F. L. Plummer, Hammond Iron Works. *Petro. Ref.*, **28,** No. 10, 97-106 (1949) Oct.

Discussion of use of aluminum in attacking high costs resulting from corrosion as well as its advantages includes properties and uses of aluminum alloys, shop fabricated storage and process vessels, aluminum piping and pipelines, galvanic action between steel and aluminum, aluminum roofs on bolted tanks, aluminum roofs on riveted tanks, field welding of aluminum roofs, recommended designs for aluminum roofs and comparative costs. 13 references.—INCO.

6.4, 1.8, 4.3

The Dissolution of Aluminum in Sodium Hydroxide Solutions. II. Michael A. Streicher. *J. of the Electrochem. Soc.*, **96,** 170-194 (1949) Sept.

Considers the effect of impurities, of solium-hydroxide concentration, of temperature and agitation on alloy, and of external current on the above. Includes electrode potential measurements. Data are tabulated and plotted. 31 ref.—BLR.

6.4, 5.9

Treatment of Aluminum for Corrosion Prevention. Arthur A. Vernon. *J. Chem. Education*, **26,** No. 3, 147-148 (1949).

Methods and theories concerning the formation of corrosion-inhibiting surfaces on aluminum are briefly reviewed. —MA.

6.4, 5.9, 5.4

Research on Aluminum and Aluminum Alloys. Vereinigte Aluminum-Werke. PB. 70016, Microfilm Reel No. G 4, Frames 5211-7080; Board of Trade, Ger. Div.,, 1949, FDX. 452, 55 pp.

The film consists of 394 reports on aluminum and its alloys, covering, in addition to metallurgical investigations, work on protective and decorative coatings, including anodic and chemical treatments, paints and lacquers.—RPI.

6.4, 1.3, 5.3, 5.9

Aluminum and Aluminum Alloys. M.—Corrosion Protection of Aluminum and Aluminum Alloys. W. Wiederholt. (In German.) FIAT Rev. German Sci., 1939-1946: Non-Ferrous Metallurgy. I, **1948,** 187-191.

A comprehensive review, with references. Separate sections deal with: 1) Metallic coatings, including a) cladding, b) electrodeposition, with special reference to hard chromium plating, c) spraying processes. 2) Protective films formed by chemical treatment—the M.B.V. process. 3) Protective films formed by electrochemical treatment, including the Eloxal and Seophoto processes, and the effect of surface condition of the basis metal on the structure and the mechanical and corrosion-resisting properties of the films produced.—MA.

6.4, 5.9

Aluminum—Its Surface Preparation and Finishing, Part I. E. R. Yarham. *Prod. Fin.*, **13,** 38-52 (1949) Sept.

Described in this article are methods of cleaning and degreasing and also the first two of the various finishing processes which are divided into four main sections—mechanical, chemical, electroplating and paint finishes. Organic solvents, alkali solutions, or combinations of these two are used for cleaning and degreasing and application of the liquids is made by hand swabbing, immersion dipping, or vapor spraying. Mechanical finishing processes, including grinding, sandblasting, shot blasting, scratch brushing and barrel polishing are discussed. Chemical surface treatment is covered in a discussion of the "Normal Process." The method of finishing to be applied depends upon 1) the nature of the materials used and the treatment they have received previously, and 2) the purpose, appearance, and service conditions of the completed article or structure.—TDD.

• Non-Metallic

6.5, 3.3

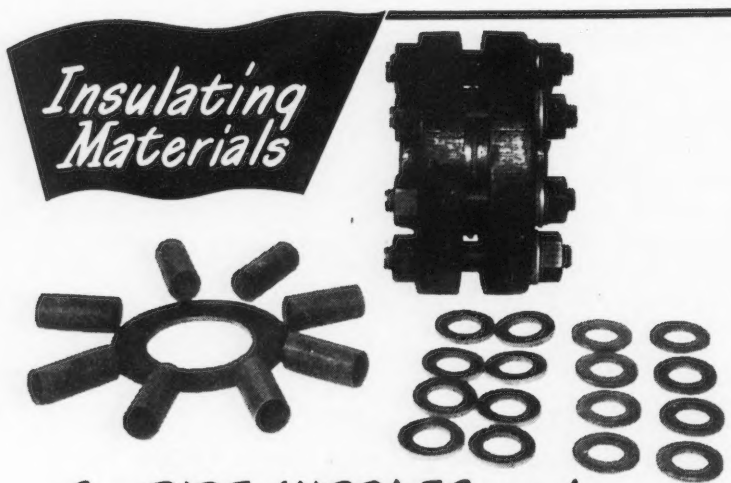
Tropical Deterioration of Equipment and Materials. PB. 81801, Frames 1-91; Board of Trade, ORR. 60/49. Office of Scientific Research & Development.

Information is given on the fungal resistance of pure resins and plasticizers and the effect of the addn. of fungicides. —RPI.

6.5

Reducing the Inflammability of Wood. I. G. Farbenindustrie. PB. 25616, Frames 186; *Prev. Det. Abs.*, **6,** W 20 (1949).

The inflammability of wood can be reduced by coating with a bentonite gel which may be mixed with pigts., e.g. lithopone, aluminum and other metal powders and fillers. A finely divided bentonite which is capable of swelling is suspended in water to give a 0.1-3% sol. This is freed from coarse grains by settling or by centrifuging and is then concentrated by evaporation to produce a 2-15% gel.—RPI.



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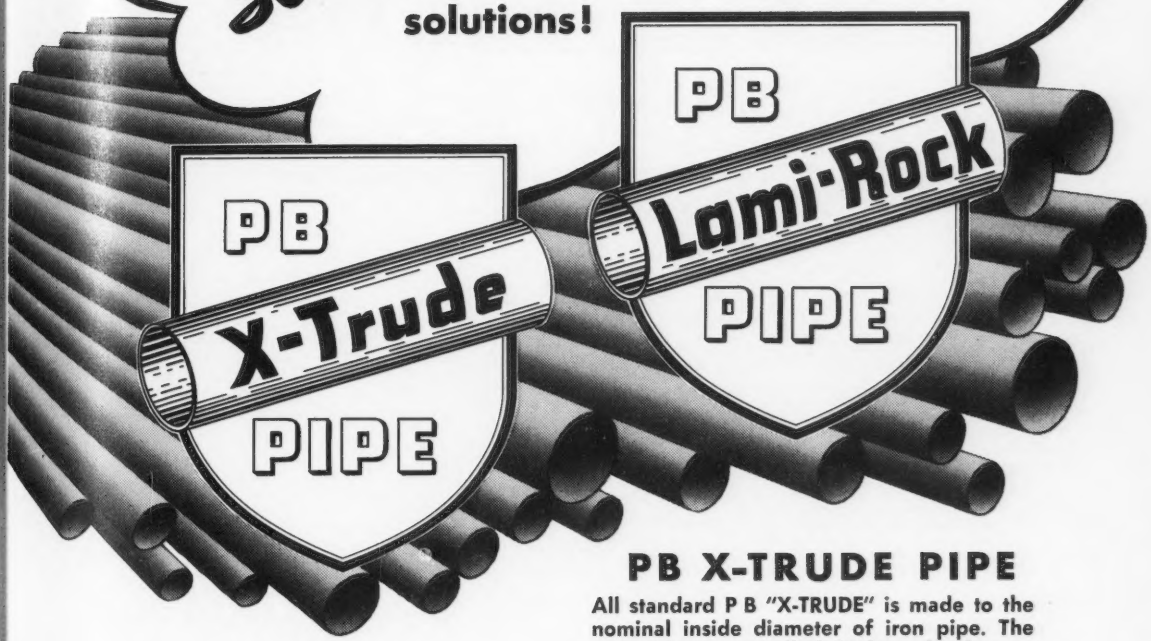

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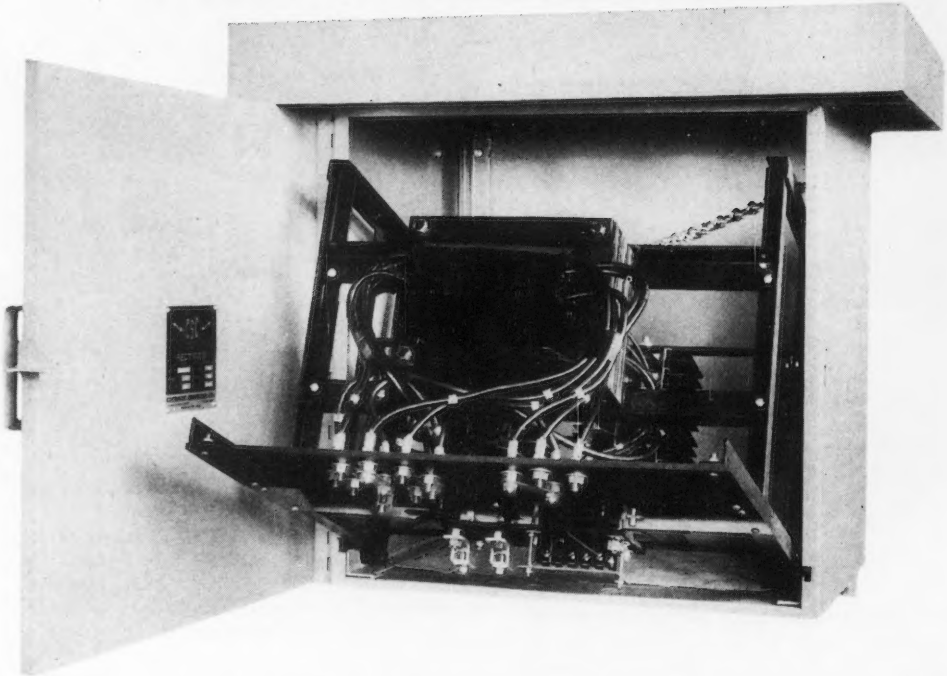

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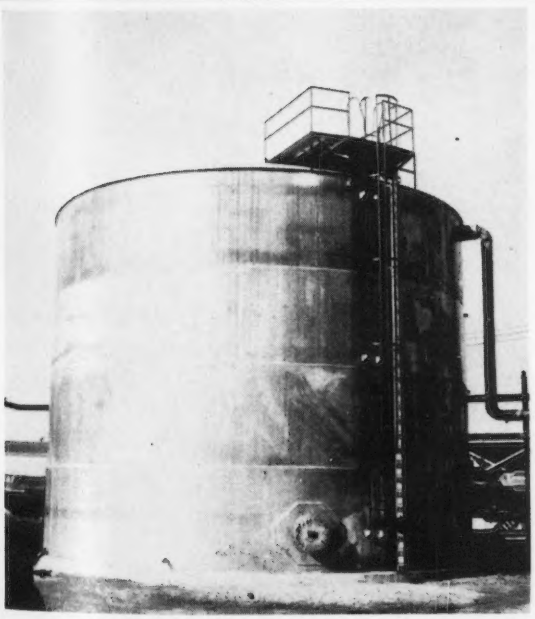

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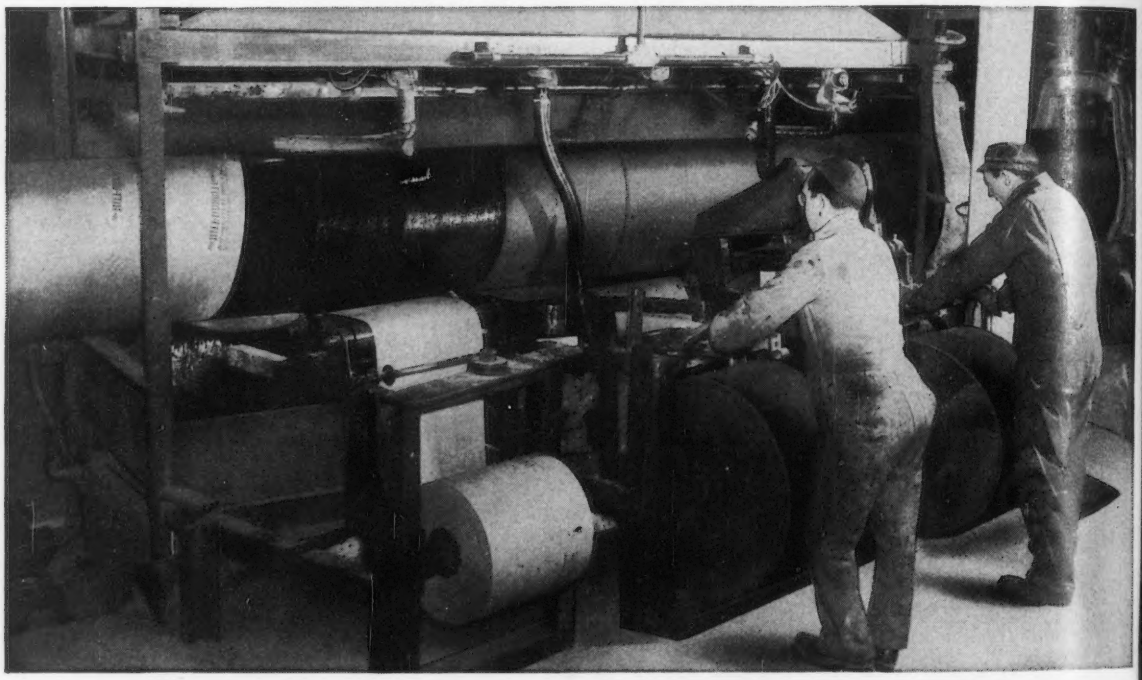

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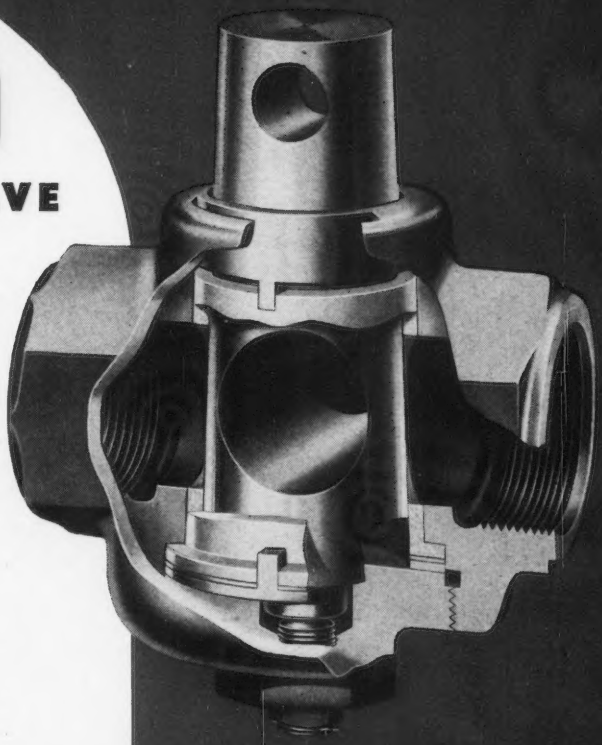

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